-NAVAL FACILITIES
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DESIGN MANUAL

STRUCTURAL ENGINEERING

NAVFAC DM-2
October 1970

Kept up-to-date with insertions (See next page.)

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
WASHINGTON, D. C. 20390

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Change No.	Date of Change	Date entered	Signature of person entering Change
1	July 1971	5/17/72	Clara E. Castelo

ABSTRACT

Basic criteria are presented on structural engineering design for naval shore facilities. Information pertains to directions and standards for procedures; methods; systems; dimensions; composite structures; materials (concrete, wood, steel, aluminum, masonry, plastic, gypsum, and copper base alloys); loads and stresses; dead loads; live loads; and meteorological data.

FOREWORD

This design manual for structural engineering is one of a series developed from an extensive reevaluation of facilities of the Shore Establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command, other Government agencies, and private industry. The manual includes a modernization of the former criteria, and the maximum use of national professional society, association, and institute codes. Deviations from these criteria should not be made without the prior approval of the Naval Facilities Engineering Command Headquarters (NAVFAC HQ).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, this edition of *Structural Engineering*, NAVFAC DM-2, cancels and supersedes *Structural Engineering*, NAVFAC DM-2 of December 1967, in its entirety, and Change 1 of May 1968.

W M Enger

W. M. Enger
Rear Admiral, CEC, USN
Commander
Naval Facilities Engineering Command

PREFACE

Basic criteria are presented in this publication for structural engineering design, and specific design criteria are included for the structural requirements common to structures in various facility classes of the category codes. Structural engineering criteria that relate only to structures in a single facility class are given in the manual covering that facility class. These criteria, together with the definitive designs and guideline specifications of the Naval Facilities Engineering Command, constitute the Commands design guidance. These standards are based on functional requirements, engineering judgement, knowledge of materials and equipment, and the experience gained by the Naval Facilities Engineering Command and other commands and bureaus of the Navy in the design, construction, operation, and maintenance of naval shore facilities.

The design manual series presents criteria that shall be used in the design of facilities under the cognizance of the Naval Facilities Engineering Command. The direction and standards for procedures, methods, dimensions, materials, loads, and stresses will be included. Design manuals are not textbooks, but are for the use of experienced architects and engineers. Many criteria and standards appearing in technical texts issued by Government agencies, professional architectural and engineering groups, and trade and industry groups are suitable for, and have been made integral parts of, this series. The latest edition of each publication source shall be used.

Bibliographies of publications containing background information and additional reading on the various subjects are included in the manuals; this material however is not a part of the criteria, nor is a reading of these sources necessary for the use of the criteria presented in the manuals.

To avoid duplication and to facilitate future revisions, criteria are presented only once in this series as far as possible. Criteria having general applications appear in the basic manuals numbered DM-1 through DM-10 (numbers DM-11 through DM-20 were unassigned in the original issues). Manuals numbered DM-21 and above contain criteria that usually are applicable only to the specific facility class covered by each manual. When criteria for one facility also have an application in another facility class, the basic rule has been to present such criteria in the basic, or lowest numbered, manual and cite it by reference where required in later manuals.

The specific design manuals (DM-21 and above), with but three exceptions, list design criteria for specific facilities in the order of the category codes. The exceptions are:

(1) *Drydocking Facilities*, NAVFAC DM-29, which includes both Category Codes 213 and 223.

(2) Criteria for facility class 800, *Utilities and Ground Improvements*, which have been included in the basic manuals on mechanical, electrical, and civil engineering.

(3) *Weight Handling Equipment and Service Craft*, NAVDOCKS DM-38, which includes the design criteria for these facilities under the cognizance of the Naval Facilities Engineering Command that are not classified as real property. These include weight and line handling equipment, dredges, yard craft, and pile driving equipment.

For the effective use of these criteria, the designer must have access to:

(1) The basic and specific design manuals applicable to the project. See list on page 2-viii.

(2) Published criteria sources.

(3) Applicable definitive design, *Definitive Designs for Naval Shore Facilities*, NAVDOCKS P-272.

(4) Command guideline specifications.

LIST OF DESIGN MANUALS

BASIC MANUALS

Title	*Number*
Architecture	NAVDOCKS DM-1
Civil Engineering	NAVFAC DM-5
Cold Regions Engineering	NAVFAC DM-9
Cost Data for Military Construction	NAVDOCKS DM-10
Drawings and Specifications	NAVFAC DM-6
Electrical Engineering	NAVFAC DM-4
Fire Protection Engineering	NAVDOCKS DM-8
Mechanical Engineering	NAVFAC DM-3
Soil Mechanics, Foundations, and Earth Structures	NAVFAC DM-7
Structural Engineering	NAVFAC DM-2

SPECIFIC MANUALS

Administrative Facilities	NAVFAC DM-34
Airfield Pavements	NAVFAC DM-21
Communications, Navigational Aids, and Airfield Lighting	NAVFAC DM-23
Community Facilities	NAVFAC DM-37
Drydocking Facilities	NAVFAC DM-29
Family Housing	NAVFAC DM-35
Harbor and Coastal Facilities	NAVFAC DM-26
Hospital and Medical Facilities	NAVFAC DM-33
Land Operational Facilities	NAVFAC DM-24
Liquid Fueling and Dispensing Facilities	NAVFAC DM-22
Maintenance Facilities	NAVFAC DM-28
Production Facilities	NAVDOCKS DM-30
Research, Development, and Test Facilities	NAVFAC DM-31
Supply Facilities	NAVFAC DM-32
Training Facilities	NAVFAC DM-27
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Waterfront Operational Facilities	NAVFAC DM-25
Weight Handling Equipment and Service Craft	NAVDOCKS DM-38

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CHAPTER 7. COMPOSITE STRUCTURES

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Figure or Table	Acknowledgments
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Table 1-2	*Minimum Design Loads in Buildings and Other Structures*, American Standards Association, New York, N. Y.
Table 1-3	*Structural Engineering*, Public Buildings Administration, Washington, D. C.
Table 1-4	*Steel Construction*, American Institute of Construction, New York, N. Y.
Figure 2-3	*45-Year Corrosion Study*, National Bureau of Standards, Washington, D. C.
Table 3-3	Lin, T. Y., *Prestressed Concrete Structures*, John Wiley & Sons, Inc., New York, N. Y.
Table 3-4	*Lightweight Concrete Information Sheet No. 5*, Expanded Shale, Clay and Slate Institute, Washington, D. C.
Table 4-4	*Engineering News Record*, June 26, 1958, McGraw-Hill Book Company, Inc., New York, N. Y.
Figure 5-1	Hill, H. N., Clark, J. W., Brungraber, R. J., *Design of Welded Aluminum Structures*, Journal of the Structural Division, ASCE, New York, N. Y.
Table 6-2 Figure 6-1	*Requirements for Concrete-Masonry Construction* (Rev. of NBS Report 2462) National Bureau of Standards, Washington, D. C.
Figure 9-1	Abbett, R. W., *American Civil Engineering Practice, Vol. III*, John Wiley & Sons, Inc., New York, N. Y.

Figure or Table	*Acknowledgments*
Figures 9-11 through 9-20	Abbett, R. W., *American Civil Engineering Practice, Vol. III,* and Shedd, T. C., *Structural Design in Steel*, John Wiley & Sons, Inc., New York, N. Y.
Figure 9-23	Abbett, R. W., *American Civil Engineering Practice, Vol. III*, John Wiley & Sons, Inc., New York, N. Y.
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Figure 9-33	*Design of Barrel Shell Roofs*, Portland Cement Association, Chicago, Ill.
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Figure 9-39	Hool, G. A., and Kinne, W. S., *Reinforced Concrete and Masonry Structures*, McGraw-Hill Book Company, Inc., New York, N. Y.
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CHAPTER 1. LOADS

Section 1. SCOPE AND RELATED CRITERIA

1. **SCOPE.** Loading criteria, as presented herein, are necessary for the design of structures and component parts.

a. **Cancellation.** This edition of *Structural Engineering*, NAVFAC DM-2, cancels and supersedes *Structural Engineering*, NAVFAC DM-2, of December 1967 in its entirety, and change 1 of May 1968.

b. **Coordination.** Policies, obligations, and responsibilities of other commands or offices (or both) are referred to only as they affect Naval Facilities Engineering Command (NAVFAC) projects.

2. **RELATED CRITERIA.** Certain criteria related to loads appear in other chapters of this design manual and in other manuals in the design manual series, as cited below:

Subject	*Source*
Bomb and blast loads	Chapter 9
Earth pressures and foundation structures	NAVFAC DM-7
Friction forces and factor of safety against sliding foundations on earth	NAVFAC DM-7
Loads on cranes, derricks, and monorails.............	NAVDOCKS DM-38
Torque load (equipment supports)	Chapter 9
Vertical loads and impact on crane runways and supports.	NAVDOCKS DM-38
Wave and current forces	NAVFAC DM-25 NAVFAC DM-26
Wind forces on ships	NAVFAC DM-25 NAVFAC DM-26

Section 2. DEAD LOADS

1. **DEFINITION.** Dead load is the term for the weights of all materials comprising a structure, including the weights of all integral and immovable items and equipment. This loading is always vertically down.

2. **UNIT WEIGHTS.** Unit weights of construction materials are listed in Table 1-1. Minimum design dead loads for assembled elements of construction are provided in Table 1-2.

3. **ALLOWANCES FOR PARTITIONS.** Fixed partitions (15 pounds per square feet (psf) or heavier) shall be considered as concentrated live loads and shall not be included in the stipulated allowances. To accommodate partitions (other than those of light wood or metal) that are not definitely included in the designs of floors where floor live loads do not exceed 80 psf, add a uniformly distributed load of 20 psf to dead load factors for floors in the following types of structures:

(1) Office buildings.

(2) Public buildings.

(3) Other structures where floors must support movable partitions that may be shifted without reference to the arrangements of floor beams or girders.

Section 3. LIVE LOADS

1. **FLOOR LOADS.** Floor loads are either uniformly distributed or concentrated. The criteria for these loads are as follows.

a. **Uniformly Distributed Loads.** A uniformly distributed load shall be the maximum average load allowed on a floor; it is determined by the type of occupancy or use. Loads given in the tables are for general guidance only; if the actual load is known to be greater, it should be used.

TABLE 1-1
Unit Weights

Material	pcf	Material	pcf
Metals, alloys, ores:		Redwood, California	26
Aluminum, cast, hammered	165	Spruce, white, black	27
Brass, cast, rolled	534	Walnut, black	38
Bronze, 7.9 to 14% Sn	509	Walnut, white	26
Bronze, aluminum	481	Masonry:	
Copper, cast, rolled	556	Cast-stone masonry (cement, stone, sand)	144
Copper ore, pyrites	262	Cinder fill	57
Gold, cast, hammered	1205	Concrete, plain:	
Iron, cast, pig	450	Cinder	108
Iron, wrought	485	Expanded-slag aggregate	100
Iron, spiegeleisen	468	Haydite (burned-clay aggregate)	90
Iron, ferrosilicon	437	Slag	132
Iron ore, hematite	325	Stone (including gravel)	144
Iron ore, hematite in bank	160-180	Vermiculite and perlite aggregate non-load-bearing	25-50
Iron ore, hematite loose	130-160		
Iron ore, limonite	237	Other light aggregate, load-bearing	70-105
Iron ore, magnetite	315	Concrete, reinforced:	
Iron slag	172	Cinder	111
Lead	710	Slag	138
Lead ore, galena	465	Stone (including gravel)	150
Magnesium, alloys	112	Ashlar masonry:	
Manganese	475	Granite, syenite, gneiss	185
Manganese ore, pyrolusite	259	Limestone, marble	160
Mercury	849	Sandstone, bluestone	140
Monel metal	556	Mortar rubble masonry:	
Nickel	565	Granite, syenite, gneiss	155
Platinum, cast, hammered	1330	Limestone, marble	150
Silver, cast, hammered	656	Sandstone, bluestone	130
Tin, cast, hammered	459	Dry rubble masonry:	
Tin ore, cassiterite	418	Granite, syenite, gneiss	130
Zinc, cast, rolled	440	Limestone, marble	125
Zinc ore, blende	253	Sandstone, bluestone	110
Timber, U. S. seasoned:		Brick masonry:	
Moisture content by weight:		Pressed brick	140
(Seasoned timber, 15 to 20%;		Common brick	120
green timber, up to 50%.)		Soft brick	100
Ash, white, red	40	Concrete masonry:	
Cedar, white, red	22	Cement, stone, sand	144
Chestnut	41	Cement, slag, etc.	130
Cypress	30	Cement, cinder, etc.	100
Fir, Douglas	32	Various building materials:	
Fir, eastern	25	Ashes, cinders	40-45
Elm, white	45	Cement, portland, loose	90
Hemlock	29	Cement, portland, set	183
Hickory	49	Lime, gypsum, loose	53-64
Locust	46	Mortar, set	103
Maple, hard	43	Slags, bank slag	67-72
Maple, white	33	Slags, bank screenings	98-117
Oak, chestnut	54	Slags, machine slag	96
Oak, live	59	Slags, slag sand	49-55
Oak, red, black	41	Terra cotta, architectural:	
Oak, white	46	Voids filled	120
Pine, Oregon	32	Voids unfilled	72
Pine, red	30	Earth, excavated:	
Pine, white	26	Clay, dry	63
Pine, yellow, long-leaf	44	Clay, damp, plastic	110
Pine, yellow, short-leaf	38	Clay and gravel, dry	100
Poplar	30	Earth, dry, loose	76

TABLE 1-1 (Continued)
Unit Weights

Material	pcf	Material	pcf
Earth, dry, packed	95	Coal, charcoal pine	23
Earth, moist, loose	78	Coal, charcoal, oak	33
Earth, moist, packed	96	Coal, coke	75
Earth, mud, flowing	108	Graphite	131
Earth, mud, packed	115	Paraffin	56
Riprap, limestone	80-85	Petroleum	54
Riprap, sandstone	90	Petroleum, refined	50
Riprap, shale	105	Petroleum, benzine	46
Sand, gravel, dry, loose	90-105	Petroleum, gasoline	42
Sand, gravel, dry, packed	100-120	Pitch	69
Sand, gravel, dry, wet	118-120	Tar, bituminous	75
Excavations in water:		Coal and coke, piled:	
Sand or gravel	60	Coal, anthracite	47-58
Sand or gravel and clay	65	Coal, bituminous, lignite	40-54
Clay	80	Coal, peat, turf	20-26
River mud	90	Coal, charcoal	10-14
Soil	70	Coal, coke	23-32
Stone riprap	65	Various solids:	
Minerals:		Cereals, oats–bulk	32
Asbestos	183	Cereals, barley–bulk	39
Barytes	281	Cereals, corn, rye–bulk	48
Basalt	184	Cereals, wheat–bulk	48
Bauxite	159	Hay and straw – bales	20
Borax	109	Cotton, flax, hemp	93
Chalk	137	Fats	58
Clay, marl	137	Flour, loose	28
Dolomite	181	Flour, pressed	47
Feldspar, orthoclase	159	Glass, common	156
Gneiss, serpentine	159	Glass, plate or crown	161
Granite, syenite	175	Glass, crystal	184
Greenstone, trap	187	Leather	59
Gypsum, alabaster	159	Paper	58
Hornblende	187	Potatoes, piled	42
Limestone, marble	165	Rubber, caoutchouc	59
Magnesite	187	Rubber goods	94
Phosphate rock, apatite	200	Salt, granulated, piled	48
Porphyry	172	Saltpeter	67
Pumice, natural	40	Starch	96
Quartz, flint	165	Sulfur	125
Sandstone, bluestone	147	Wool	82
Shale, slate	175	Various liquids:	
Soapstone, talc	169	Alcohol, 100%	49
Stone, quarried, filled:		Acid, muriatic, 40%	75
Basalt, granite, gneiss	96	Acid, nitric, 91%	94
Limestone, marble, quartz	95	Acid, sulfuric, 87%	112
Sandstone	82	Lye, soda, 66%	106
Shale	92	Oil, vegetable	58
Greenstone, hornblende	107	Oil, creosote	65
Bituminous substances:		Oil, fuel	60.6
Asphaltum	81	Oil, gasoline	46
Coal, anthracite	97	Water, 4° C, max density	62.428
Coal, bituminous	84	Water, sea water	64
Coal, lignite	78	Water, ice	56
Coal, peat, turf, dry	47	Water, snow, fresh fallen	8

TABLE 1-2

Minimum Design Dead Loads for Assembled Elements of Construction

Walls:[1]	psf
4-inch clay brick, high absorption	34
4-inch clay brick, medium absorption	39
4-inch clay brick, low absorption	46
4-inch sand-lime brick	38
4-inch concrete brick, heavy aggregate	46
4-inch concrete brick, light aggregate	33
8-inch clay brick, high absorption	69
8-inch clay brick, medium absorption	79
8-inch clay brick, low absorption	89
8-inch sand-lime brick	74
8-inch concrete brick, heavy aggregate	89
8-inch concrete brick, light aggregate	68
12½-inch clay brick, high absorption	100
12½-inch clay brick, medium absorption	115
12½-inch clay brick, low absorption	130
12½-inch sand-lime brick	105
12½-inch concrete brick, heavy aggregate	130
12½-inch concrete brick, light aggregate	98
4-inch brick, 4-inch load-bearing structural clay tile backing	60
4-inch brick, 8-inch load-bearing structural clay tile backing	75
8-inch brick, 4-inch load-bearing structural clay tile backing	102
8-inch load-bearing structural clay tile	42
12-inch load-bearing structural clay tile	58
8-inch concrete block, heavy aggregate	55
12-inch concrete block, heavy aggregate	85
8-inch concrete block, light aggregate	35
12-inch concrete block, light aggregate	55
2-inch furring tile, one side of masonry wall, add to above figures.	12

Partitions:[1]	psf
3-inch clay tile	17
4-inch clay tile	18
6-inch clay tile	28
8-inch clay tile	34
10-inch clay tile	40
2-inch facing tile	15
4-inch facing tile	25
6-inch facing tile	38
2-inch gypsum block	9½
3-inch gypsum block	10½
4-inch gypsum block	12½
5-inch gypsum block	14
6-inch gypsum block	18½
2-inch solid plaster	20
4-inch solid plaster	32
4-inch hollow plaster	22
4-inch concrete block, heavy aggregate	30

Partitions:[1] (Continued)	psf
6-inch concrete block, heavy aggregate	42
8-inch concrete block, heavy aggregate	55
12-inch concrete block, heavy aggregate	85
4-inch concrete block, light aggregate	20
6-inch concrete block, light aggregate	28
8-inch concrete block, light aggregate	38
12-inch concrete block, light aggregate	55
Wood studs, 2 × 4, unplastered	1.6
Wood studs, 2 × 4, plastered one side	12
Wood studs, 2 × 4, plastered two sides	20
Glass block masonry:	
4-inch glass-block walls and partitions	18
Split furring tile:	
1½-inch	8
2-inch	8½
Concrete slabs:	
Concrete, reinforced-stone, per inch of thickness.	12½
Concrete, reinforced-cinder, per inch of thickness.	9¼
Concrete, reinforced, lightweight, per inch of thickness.	9
Concrete, plain stone, per inch of thickness	12
Concrete, plain cinder, per inch of thickness.	9
Concrete, plain, lightweight, per inch of thickness.	8½

Ribbed slabs:

Depth in inches (rib depth ± slab thickness)	Width of rib in inches (psf) 4	5	6	7	Add for tapered ends
20-inch metal fillers:					
6 plus 2	39	42	44	....	4
8 plus 2½	51	54	57	....	5
10 plus 3	63	67	70	....	5
12 plus 3	69	74	78	....	5
14 plus 3	75	81	86	....	5
30-inch metal fillers:					
6 plus 2½	....	43	45	47	3
8 plus 2½	....	48	50	52	4

[1] See footnote at end of table.

TABLE 1-2 (Continued)

Minimum Design Dead Loads for Assembled Elements of Construction

Ribbed slabs:					
Depth in inches (rib depth ± slab thickness)	Width of rib in inches				Add for tapered ends
	psf				
30-inch metal fillers:					
10 plus 3	....	59	62	64	4
12 plus 3	....	63	67	70	4
14 plus 3	....	69	73	77	4
2-way clay tile fillers: (12 × 12):					
4 plus 2	61	62	64	....	....
6 plus 2	87	89	90	....	....
8 plus $2\frac{1}{2}$	100	103	107	....	....
10 plus 3	121	126	131	....	....
12 plus 3	136	141	146	....	....
2-way metal fillers: (16 × 16):					
4 plus 2	44	47	50	....	....
6 plus 2	55	60	63	....	....
8 plus $2\frac{1}{2}$	72	78	83	....	....
10 plus 3	91	96	103	....	....
12 plus 3	103	111	118	....	....
14 plus 3	116	125	133	....	....
2-way metal fillers: (20 × 20):					
4 plus 2	42	44	46	....	....
6 plus 2	50	54	58	....	....
8 plus $2\frac{1}{2}$	66	71	76	....	....
10 plus 3	83	88	94	....	....
12 plus 3	93	100	107	....	....
14 plus 3	105	113	120	....	....
12-inch clay tile fillers:					
4 plus 2	49	51	52	54	....
6 plus 2	60	63	65	67	....
8 plus $2\frac{1}{2}$	79	82	85	87	....
10 plus 3	96	100	103	106	....
12 plus 3	108	112	116	120	....

Floor finish and fill	Finish floor to top slab in.	Load, psf
Linoleum on stone-concrete fill	4	46
Linoleum on stone-concrete fill	5	58
Linoleum on light-concrete fill	4	27
Linoleum on light-concrete fill	5	34
Double $\frac{7}{8}$-inch wood on sleepers, light concrete fill.	4	19
Double $\frac{7}{8}$-inch wood on sleepers, light concrete fill.	5	26
Double $\frac{7}{8}$-inch wood on sleepers, stone-concrete fill.	4	28
Double $\frac{7}{8}$-inch wood on sleepers, stone-concrete fill.	5	40
Single $\frac{7}{8}$-inch wood on sleepers, light concrete fill.	4	23
Single $\frac{7}{8}$-inch wood on sleepers, light concrete fill.	5	30
Single $\frac{7}{8}$-inch wood on sleepers, stone-concrete fill.	4	40
Single $\frac{7}{8}$-inch wood on sleepers, stone-concrete fill.	5	50
3-inch wood block on mastic, no fill.	3	10
$\frac{7}{8}$-inch wood block on stone-concrete fill.	4	40
1-inch cement finish on stone-concrete fill.	4	48
1-inch terrazzo on stone-concrete fill.	4	48
Clay tile on stone-concrete fill.	4	48
Marble and mortar on stone-concrete fill.	4	50

Floor finish	Thickness in.	Load, psf
$1\frac{1}{2}$-inch asphalt mastic flooring	$1\frac{1}{2}$	18
3-inch wood block on $\frac{1}{2}$-inch mortar base.	$3\frac{1}{2}$	16
Solid flat tile on 1-inch mortar base.	2	23
2-inch asphalt block, $\frac{1}{2}$-inch mortar.	$2\frac{1}{2}$	30
1-inch terrazzo, 2-inch stone concrete.	3	38

[1] See footnote at end of table.

TABLE 1-2 (Continued)

Minimum Design Dead Loads for Assembled Elements of Construction

Floor finish (Continued)	Thickness in.	Load, psf
Waterproofing:		
Five-ply membrane	½	5
Five-ply membrane, mortar, stone concrete.	5	55
2-inch split tile, 3-inch stone concrete.	5	45
Floor fill:		
Cinder concrete, per inch	....	9
Lightweight concrete, per inch	....	7
Sand, per inch	....	8
Stone concrete, per inch	....	12
Wood joist floors (no plaster) double wood floor	**12-inch spacing, psf**	**16-inch spacing, psf**
Joist sizes, in inches:		
2 × 6	6	5
2 × 8	6	6
2 × 10	7	6
2 × 12	8	7
3 × 6	7	6
3 × 3	8	7
3 × 10	9	8
3 × 12	11	9
3 × 14	12	10

Ceilings:	psf
Plaster on tile or concrete	5
Suspended metal lath and gypsum plaster	10
Suspended metal lath and cement plaster	15
Plaster on wood lath	8
Roof and wall coverings:	**psf**
Clay tile (for mortar add 10 lb):	
2-inch book tile	12
3-inch book tile	20
Roman	12
Spanish	19
Ludovici	10
Composition:	
Three-ply ready roofing	1
Four-ply felt and gravel	5½
Five-ply felt and gravel	6
Copper or tin	1
Corrugated asbestos-cement roofing	4
Corrugated iron	2
Fiberboard, ½-inch	¾
Gypsum sheathing, ½-inch	2
Skylight, metal frame, ⅜-inch wire glass	8
Slate, 3/16-inch	7
Slate, ¼-inch	10
Wood sheathing, per inch thickness	3
Wood shingles	3
Asphalt shingles	6
Cement asbestos shingles	4
Cement tile	16

[1] For masonry construction add 5 psf for each face plastered.

(1) *Human and Special Occupancy.* Live load requirements for human and special occupancy are listed in Table 1-3.

(2) *Warehouses.* Live loads for storage warehouses are specified in Table 1-4.

b. Concentrated Loads. Unless otherwise specified, assume that concentrated loads occupy spaces 2.5 by 2.5 feet, and that they are placed to develop maximum stresses in the affected members. Design all floors to support either uniformly distributed loads or concentrated loads (whichever develops the greater stresses) as follows:

Designation	*Load*
Elevator machine room grating	300 pounds on an area of 4 square inches.
Finish light floor plate	200 pounds on an area of 1 square inch.
Floors other than those above..	2,000 pounds.
Scuttles, skylights, and accessible ceilings	200 pounds.

Use actual load if it exceeds those given above.

2. STAIR, SIDEWALK, AND DRIVEWAY LOADS.

Design stairs, sidewalks, and driveways to support uniformly distributed or concentrated loads.

a. Stair. Apply either a uniformly distributed load of 100 psf or a concentrated load of 300 pounds on center of tread, depending on anticipated usage.

b. Sidewalk. Apply either a uniformly distributed load of 250 psf or, when subject to trucking, a concentrated load of 8,000 pounds (whichever develops the greater stresses) on an area of 2.5 by 2.5 feet.

c. Driveway. Apply either a uniformly distributed load of 250 psf or the heaviest wheel load expected (minimum 12,000 pounds) in a driveway, whichever develops the greater stresses.

3. ROOF LOADS.

Because roofs are exposed to varying environmental conditions, depending on their location, they should be designed to support loads imposed by the prevailing climatic conditions.

a. Uniform Loads.

(1) *Minimum Load.* Design roofs to support a minimum load of 20 psf. Where snow conditions exist, design roofs to support the loads indicated in Figure 1-1 and Tables 1-5 and 1-6, using horizontal projected areas. The roof live loads shall conform to snowpack on ground weights for snowpack values of 20 through 40 psf. A roof live load of 40 psf shall be used for areas where the snowpack on the ground exceeds 40 psf. (Because of interior building heat and wind effects, it is improbable that the snow load will exceed 40 psf.)

(2) *Slope Factors.* The design live load shall be reduced for roofs having a slope in excess of 20 degrees in accordance with the following formula: Reduce excess over 20 psf for each degree of slope over 20 degrees by (S/40-1/2), where S is the total snow load in psf. For example, when S = 35 psf and slope = 30 degrees,

$$S_{net} = 35 - \left(\frac{35}{40} - \frac{1}{2}\right) \times (30-20) = 31.25 \text{ psf.} \quad (1\text{-}1)$$

(3) *Wind Load.* See as described in Section 4. Uplift forces should be stated on drawings where preengineered structural components are used.

b. Special Loads. Curved roofs, multipurpose roofs, roof trusses, and roof valleys carry loads differently from ordinary roofs and shall be designed accordingly.

(1) *Curved Roofs.* The formula for determining safe snow loads on arches and curved roofs is shown in Figure 1-2.

(2) *Multipurpose Roofs.* Roofs used for secondary purposes (such as promenades, ponding, and support of equipment) shall be designed for the loads corresponding to usage.

(3) *Roof Trusses.* Simultaneously with the uniform roof loads, apply a 2,000-pound concentrated load on any lower chord panel point for roof trusses over garages, hangars, and manufacturing or storage floors.

(4) *Roof Valleys.* Increase loads for snow accumulations in valleys. The loading intensity shall be assumed twice the normal value, varying to the normal amount of 8 feet each side of trough.

(5) *Ponding.* The minimum roof slope will normally preclude ponding; however, it should be considered if possible.

4. REDUCTION IN LIVE LOADS.

a. Live Loads Exceeding 100 psf. No reductions shall be applied to floor framing members. The

TABLE 1-3

Uniform Floor Live Load Requirements for Human and Special Occupancy[1]

Occupancy or use	Live load (psf)
Apartments (see Residential)	
Apparatus room	75
Armories	150
Assembly halls and other places of assembly:	
Fixed seats	60
Movable seats	100
Automatic data processing rooms	150
Bag storage	125
Bakeries; general area	100
Bakeries; storage area	200
Balconies; exterior	100
Barber shop	75
Barracks and dormitories:	
partitioned	40
nonpartitioned, including allowances for future partitions	60
corridors	100
Battery charging room	200
Boiler houses	200
Bowling alleys, pool rooms and similar recreation areas	75
Car wash rooms	75
Canteens; general area	100
Canteens; storage area	200
Catwalks; buildings	25
Catwalks; marine	50
Ceiling; accessibly furred	10
Chapels (see Theaters and chapels)	
Cobbler shop	100
Computer rooms	200
Concentrated loads:	
Elevator machine room grating (on area of 4 sq in.)	300 lb
Finish light floor plate construction (on area of 1 sq in.)	200 lb
Main corridors, large offices, and similar areas (on 2.5 ft x 2.5 ft)	2,000 lb
Scuttles, skylight ribs, and accessible ceilings	200 lb
Sidewalks (on 2.5 ft x 2.5 ft)	8,000 lb
Stair treads (on center of tread)	300 lb
Corridors:	
First floor, except as indicated	100
Other floors, except as indicated	80
Court rooms	80
Dance floors	125
Day rooms	60
Dining rooms and restaurants	100
Kitchen; general area	75
Drawing reproduction rooms (blue printing)	100
Dressing rooms (theater)	75
Drill halls	125
Drum fillings	150
Drum washing	75
Dwellings (see Residential)	
File rooms:	
Letter files	80
Card files	125
Drawing files	200
Galleys:	
Dishwashing rooms (mechanical)	300
Provision storage (not refrigerated)	200
Preparation room:	
meat	250
vegetable	100
Garages:	
Repair areas	100
Passengers cars	100
Trucks, with load, 3 to 10 tons	150
Trucks, with load, over 10 tons	200
(Check all garage floors for 150% maximum wheel load anywhere on floor.)	
Garbage storage rooms	125
Grandstands, reviewing stands, and bleachers	100
Generator rooms	200
Guard house	75
Gymnasiums; main floor and balconies	100
Hangars:	
Land planes and seaplanes	wheel loads
Hospitals:	
Wards	40
Private rooms and miscellaneous rooms	40
Corridors; main	100
Corridors; secondary	60
Operating rooms	60
Examination rooms & doctor's offices	40
Hydrotherapy	75
Radiology	75
Physical Therapy	75
Hotels (see Residential)	
Incinerators; charging floor	150
Laboratories; normal scientific equipment	100
Latrines	75
Laundries; general areas	100
Libraries:	
Reading rooms	60
Stack rooms–20 pcf or 150 max	60
Light manufacturing areas and loft buildings	125
Linen storage	125
Lobbies, vestibules, & large waiting rms	100
Locker rooms	75
Lounges, day rooms, small recreation areas	60
Mechanical equipment rooms (general)	100

TABLE 1-3 (Continued)

Uniform Floor Live Load Requirements for Human and Special Occupancy[1]

Occupancy or use	Live load (psf)
Mechanical room (air conditioning)	125
Mechanical telephone and radio equipment rooms	150
Mess halls	100
Morgues	100
Office buildings:	
Private offices	50
Clerical offices; large	80
Corridors; main	100
Corridors; secondary	60
Lobbies	100
Files or storage	varies, 80 min
Business machine equipment	100
All main corridors, offices, business machine equipment, and storage rooms—2,000 lb concentrated load over 2.5 ft x 2.5 ft	
Penal institutions:	
Cell blocks	40
Corridors	100
Post exchanges (see Stores)	
Post offices:	
General area	100
Work rooms	125
Power plants	200
Projection booths	100
Promenade roof	60
Pump houses	100
Recreation rooms (used for dancing)	125
Recreation rooms (not used for dancing)	100
Receiving rooms (radio) including roof areas supporting antennas and electronic equipment	150
Refrigeration storage rooms:	
Dairy	200
Meat	250
Vegetables	275
Rest rooms	60
Residential:	60
Corridors and porches	60
Toilet areas	40
Multifamily houses:	
private apartments	40
public rooms	100
corridors	60
Dwellings:	
first floor	40
second floor and habitable attics	30
uninhabitable attics	20
stairs	60
Hotels and BOQs:	
guest and living rooms	40
public rooms	100
corridors serving public rooms	100
private corridors	60
Rubbish storage rooms	100
Schools:	
Classrooms	40
Corridors	100
Scrub decks	75
Shops:	
Aircraft utility	200
Assembly and repair	250 to 400
Blacksmith	125
Bombsight	125
Carpenter	125
Drum repair	100
Electrical	300
Engine overhaul	300
Heavy materials assembly	300 to 400
Light materials assembly	125
Machine	300
Mold loft	80
Plate (except storage areas)	300
Public works:	
first floor	125
sheet metal	125
shipfitters	300
structural	300
upper floors	100
Showers and washrooms	60
Stairs, platforms, fire escapes, and exitways	100
Stairs, balconies, etc. (lateral thrust at top of railing)	50 per line foot
Storage rooms and buildings	
Stores, retail:	
First floor	100
Upper floors	75
Storehouses:	
Aircraft	200
Ammunition (one story)	2,000
Cold storage:	
first floor	400
upper floors	300
Dry provisions	300
Fuse and detonator (one story)	500
General:	
first floor	600 to 1,000
second floor	400
third floor	300
above third floor	
heavy materials (one story)	
high explosives (one story)	500
inert materials (one story)	500 to 2,000
light tools	150
paint and oil (one story)	500
pipe and metals (one story)	1,000
pyrotechnics (one story)	500

TABLE 1-3 (Continued)

Uniform Floor Live Load Requirements for Human and Special Occupancy[1]

Occupancy or use	Live load (psf)	Occupancy or use	Live load (psf)
small arms (one story)	500	Theaters and chapels:	
subsistence buildings	200	Aisles, corridors, and lobbies	100
torpedo (one story)	350	Orchestra floors; fixed seats	60
Tailor shop	75	Balconies; fixed seats	60
Telephone exchange rooms:		Stage floors	150
Normal	150	Projection rooms	100
Locations subject to earth tremors, gunnery practice, or other conditions causing unusual vibrations	250	Offices and miscellaneous rooms	40
		Toilets	40
		Warehouses:[2]	
Terminal equipment buildings (all areas other than stairs, toilets, and washrooms)	150	Light storage	125
		Heavy storage	250
		Loading platforms	250 min

[1] In addition to uniform load, design must consider equipment, vehicle loads, and any other concentrated loads or special conditions due to the intended use.

[2] Use actual loads where they exceed those shown, also see Table 1-4.

TABLE 1-4
Uniform Live Loads for Storage Warehouses

Material	Weight per cubic foot of space (lb)	Height of pile (ft)	Weight per square foot of floor (lb)	Live load (psf)
Building materials:				
Asbestos	50	6	300	
Bricks, building	45	6	270	
Bricks, fire clay	75	6	450	
Cement, natural	59	6	354	300
Cement, portland	72 to 105	6	432 to 630	to
Gypsum	50	6	300	400
Lime and plaster	53	5	265	
Tiles	50	6	300	
Woods, bulk	45	6	270	
Drugs, paints, oil:				
Alum, pearl, in barrels	33	6	198	
Bleaching powder, in hogsheads	31	3½	102	
Blue vitriol, in barrels	45	5	226	
Glycerine, in cases	52	6	312	
Linseed oil, in barrels	36	6	216	
Linseed oil, in iron drums	45	4	180	
Logwood extract, in boxes	70	5	350	
Rosin, in barrels	48	6	288	
Shellac, gum	38	6	228	200
Soaps	50	6	300	to
Soda ash, in hogsheads	62	2¾	167	300
Soda, caustic, in iron drums	88	3⅜	294	
Soda, silicate, in barrels	53	6	318	
Sulphuric acid	60	1⅝	100	
Toilet articles	35	6	210	
Varnishes	55	6	330	
White lead paste, in cans	174	3½	610	
White lead, dry	86	4¾	408	
Red lead and litharge, dry	132	3¾	495	
Dry goods, cotton, wool:				
Burlap, in bales	43	6	258	
Carpets and rugs	30	6	180	
Coir yarn, in bales	33	8	264	
Cotton, in bales, American	30	8	240	
Cotton, in bales, foreign	40	8	320	
Cotton bleached goods, in cases	28	8	224	
Cotton flannel, in cases	12	8	96	
Cotton sheeting, in cases	23	8	184	
Cotton yarn, in cases	25	8	200	
Excelsior, compressed	19	8	152	200
Hemp, Italian, compressed	22	8	176	to
Hemp, Manila, compressed	30	8	240	250
Jute, compressed	41	8	328	
Linen damask, in cases	50	5	250	
Linen goods, in cases	30	8	240	
Linen towels, in cases	40	6	240	
Silk and silk goods	45	8	360	
Sisal, compressed	21	8	168	
Tow, compressed	29	8	232	
Wool, in bales, compressed	48			
Wool, in bales, not compressed	13	8	104	
Wool, worsteds, in cases	27	8	216	

TABLE 1-4 (Continued)
Uniform Live Loads for Storage Warehouses

Material	Weight per cubic foot of space (lb)	Height of pile (ft)	Weight per square foot of floor (lb)	Live load (psf)
Groceries, wines, liquors:				
Beans, in bags	40	8	320	
Beverages	40	8	320	
Canned goods, in cases	58	6	348	
Cereals	45	8	360	
Cocoa	35	8	280	
Coffee, roasted, in bags	33	8	264	
Coffee, green, in bags	39	8	312	
Dates, in cases	55	6	330	
Figs, in cases	74	5	370	
Flour, in barrels	40	5	200	250
Fruits, fresh	35	8	280	to
Meat and meat products	45	6	270	300
Milk, condensed	50	6	300	
Molasses, in barrels	48	5	240	
Rice, in bags	58	6	348	
Sal soda, in barrels	46	5	230	
Salt, in bags	70	5	350	
Soap powder, in cases	38	8	304	
Starch, in barrels	25	6	150	
Sugar, in barrels	43	5	215	
Sugar, in cases	51	6	306	
Tea, in chests	25	8	200	
Wines and liquors, in barrels	38	6	228	
Hardware:				
Automobile parts	40	8	320	
Chain	100	6	600	
Cutlery	45	8	360	
Door checks	45	6	270	
Electrical goods and machinery	40	8	320	
Hinges	64	6	384	
Locks, in cases, packed	31	6	186	
Machinery, light	20	8	160	
Plumbing fixtures	30	8	240	300
Plumbing supplies	55	6	330	to
Sash fasteners	48	6	288	400
Screws	101	6	606	
Shafting steel	125			
Sheet tin, in boxes	278	2	556	
Tools, small, metal	75	6	450	
Wire cables, on reels			425	
Wire, insulated copper, in coils	63	5	315	
Wire, galvanized iron, in coils	74	$4\frac{1}{2}$	333	
Wire, magnet, on spools	75	6	450	
Miscellaneous:				
Automobile tires	30	6	180	
Automobiles, uncrated	8		64	
Books (solidly packed)	65	6	390	
Furniture	20			
Glass and chinaware, in crates	40	8	320	
Hides and leather, in bales	20	8	160	
Leather and leather goods	40	8	320	
Paper, newspaper, and strawboards	35	6	210	

TABLE 1-4 (Continued)

Uniform Live Loads for Storage Warehouses

Material	Weight per cubic foot of space (lb)	Height of pile (ft)	Weight per square foot of space (lb)	Live load (psf)
Miscellaneous: (Continued)				
Paper, writing and calendared	60	6	360	
Rope, in coils	32	6	192	
Rubber, crude	50	8	400	
Tobacco, bales	35	8	280	

design live loads on columns may be reduced 20 percent.

b. Live Loads, 100 psf or Less. The design live load on a girder or truss (carrying primary framing members), supporting 150 square feet or more, may be reduced at a rate of 0.08 percent per square foot of area supported by the member, except that no reduction shall be made for public assembly or storage areas. A reduction shall not exceed R, as determined by equation (1-2), or 60 percent:

$$R = 100 \times \frac{D+L}{4.33L}, \qquad (1\text{-}2)$$

where

R = reduction (percent),
D = dead load per square foot of area supported by the member, and
L = design live load per square foot of area supported by the member.

Roof members may be treated as described above for uniform live load, except that in no case shall the design load be less than the actual snowpack or 12 psf, whichever is greater. This reduction does not apply to calculations for wind, seismic forces, or concentrated loads. Column and footing live loads may be reduced in accordance with values given for girders.

5. PARTIAL LOADING.

a. Uniform Distribution of Loads. In continuous framing, consideration shall be given to variations in the locations of uniform live loads in the various spans for maximum design conditions.

b. Moving Loads. All structures subject to moving or variable loads shall have each part designed with only those live loads on the structure that develop the maximum stresses in the considered part.

6. MOBILE LOADS.

a. Highway Loads. *Standard Specifications for Highway Bridges*, American Association of State Highway Officials (AASHO), (see Criteria Sources) contains standards and criteria useful in developing highway loads.

b. Railway Loads. Data for railway loads are contained in the American Railroad Engineering Association (AREA) Manual. (See Criteria Sources.)

c. Crane Runways and Supports. Crane runways and supports shall be designed to support vertical and horizontal loads delineated as follows:

(1) Vertical Loads. For wheel loads, see individual crane manufacturer's catalogs.

(2) Horizontal Loads. Lateral forces due to trolley travel shall equal 10 percent of the dead load of the trolley and 20 percent of the hook load, one-half applied at the top of each runway girder. Longitudinal forces due to crane travel shall equal 10 percent of the sum of the maximum wheel load on one runway girder.

(3) Test Loading. See NAVDOCKS DM-38 for test loading on cranes.

7. LOADS FOR SPECIAL STRUCTURES.

a. Bins and Bunkers. For loads on component parts of bins and bunkers, see *The Design of Walls, Bins, and Grain Elevators.* (See Criteria Sources.)

b. Piers, Wharves, and Waterfront Structures. Load criteria for piers, wharves, and waterfront structures are discussed in detail in *Waterfront Operational Facilities*, NAVFAC DM-25, and *Harbor and Coastal Facilities*, NAVFAC DM-26.

c. **Antenna Supports and Transmission Line Structures.**

(1) Dead Loads. Dead loads are described in Section 2.

(2) Live Load on Stairways, Walkways, and Ladders. Live Load criteria for stairways, walkways, and ladders are listed in Paragraph 7e, which follows.

(3) Wind Load. Wind load requirements are discussed in Section 4.

(4) Ice Load. The thickness of ice covering on guys, conductors, insulation, and framing supports shall be determined from Figure 1-3. Exceptions are areas known to have more severe icing conditions, such as coastal and waterfront areas that are subject to heavy sea spray, or high local precipitation. For ice load in these areas, consult local authorities.

(5) Thermal Changes. Consider changes in guy or cable sag or both due to temperature changes. See Section 6 and *Wire Rope Engineering Handbook.* (See Criteria Sources.)

(6) Pretension Forces. Consider pretension forces in guys and wires.

(7) Broken Wires. Design support structures to resist the unbalanced pull or torsion resulting from any reasonable combination of broken antenna or transmission wires. See Chapter 9 for analysis of broken guy cable.

(8) Erection Loads. Temporary erection loads are important in the design of antenna supports and transmission line structures.

(9) Earthquake. See Section 5. Consider increases in wire or guy tensions due to the vertical component of acceleration.

d. **Cranes, Derricks, and Monorails.** Load standards for cranes, derricks, and monorails are contained in *Weight Handling Equipment and Service Craft,* NAVDOCKS DM-38.

e. **Stairways, Walkways, and Ladders.** Stairways, walkways, and ladders of towers and elevated tanks shall be designed for a uniform live load of 50 pounds or a concentrated load of 350 pounds, whichever develops the greater stresses.

f. **Turbine-Generator Foundations.**

(1) Vertical Loads. For component weights of the turbine generator and distribution of these weights, refer to the manufacturer's machine outline drawings. Increase machine loads 25 percent for machines with speeds up to and including 1,800 revolutions per minute (rpm), and 50 percent for those with higher speeds. Consider additional loads (such as auxiliary equipment, pipes, and valves) supported by the foundations. Also see Chapter 9, Section B, Part 3.

(2) Steam Condenser Load. The condenser, or vacuum, load shall be determined from the method of mounting the condenser.

(3) Torque Load. See criteria on equipment supports, Chapter 9, Section 9.

(4) Horizontal Loads on Support Framing.

(a) Longitudinal force. Assume a longitudinal force of 20 to 50 percent of the machine weight applied at the shaft centerline.

(b) Transverse force. Assume a transverse force at each bent of 20 to 50 percent of the machine weight supported by the bent and applied at the machine centerline.

(c) Longitudinal and transverse forces. Longitudinal and transverse forces shall not be assumed to act simultaneously.

(5) Horizontal Forces Within Structure. Assume horizontal forces equal in magnitude to the vertical loads of the generator stator and turbine exhaust hood, as given on the manufacturer's machine outline drawings. Apply these forces at the top flange of the supporting girders; assume the forces to be equal and opposite.

(6) Assumed Forces on Centerline Guides. Refer to machine outline drawing for magnitude and points of application. Support beams for guide brackets shall have sufficient rigidity to limit the displacements relative to the main foundation to 0.005 inch under the action of the assumed forces.

(7) Temperature Variation. Consider forces acting within the foundation due to temperature changes.

(8) External Piping. Provisions shall be made to withstand loads from pipe thrusts, relief values, and the weight of piping and fittings.

8. IMPACT.

Live loads shall be increased by amounts specified as follows for dynamic, vibratory, and impact effects of applied loads.

a. **Supports for Elevators and Hoisting Apparatus.** Provide for the following increases in moving loads for elevators and hoisting apparatus:

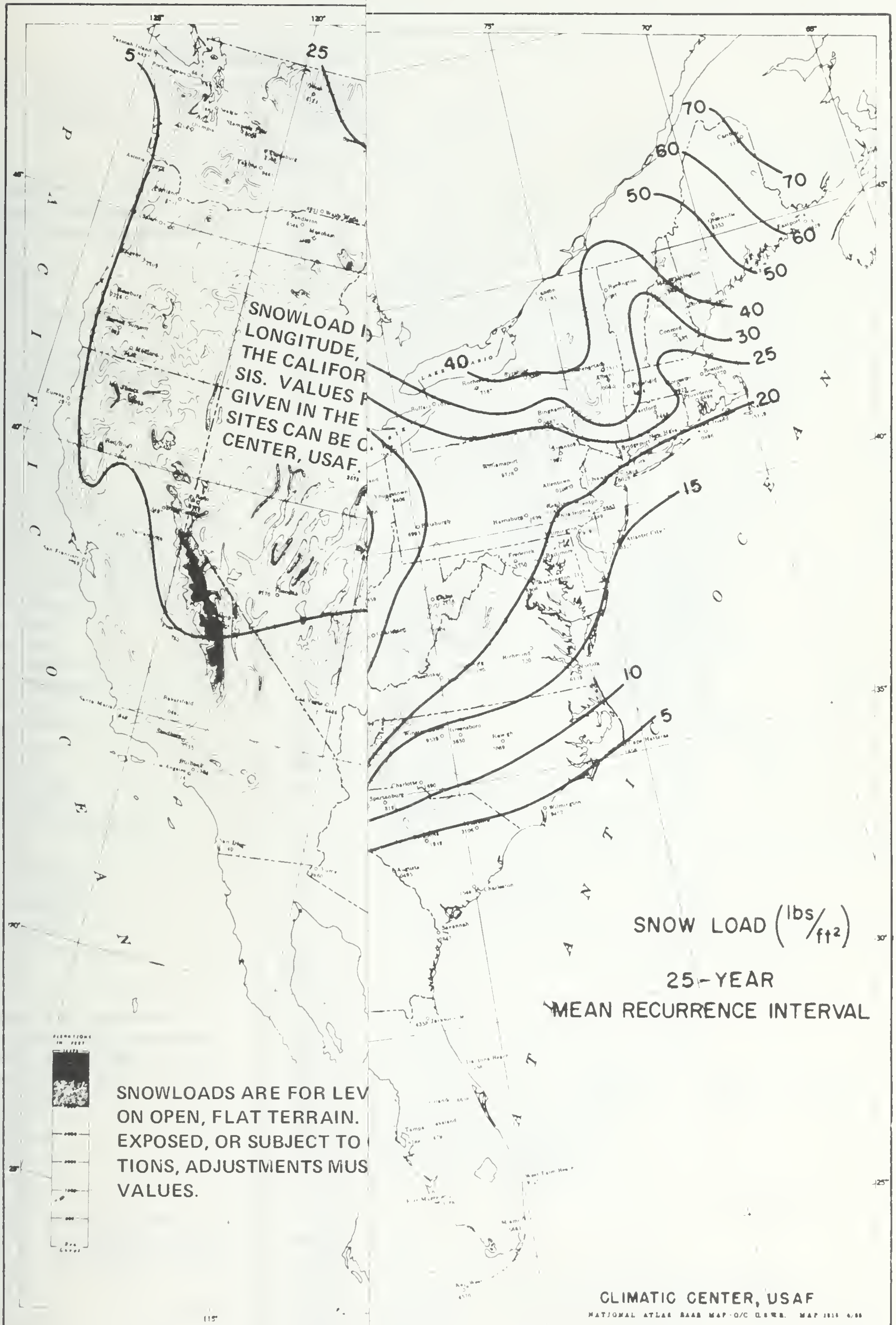


FIGURE 1-1
Snow Loadings in Contiguous States

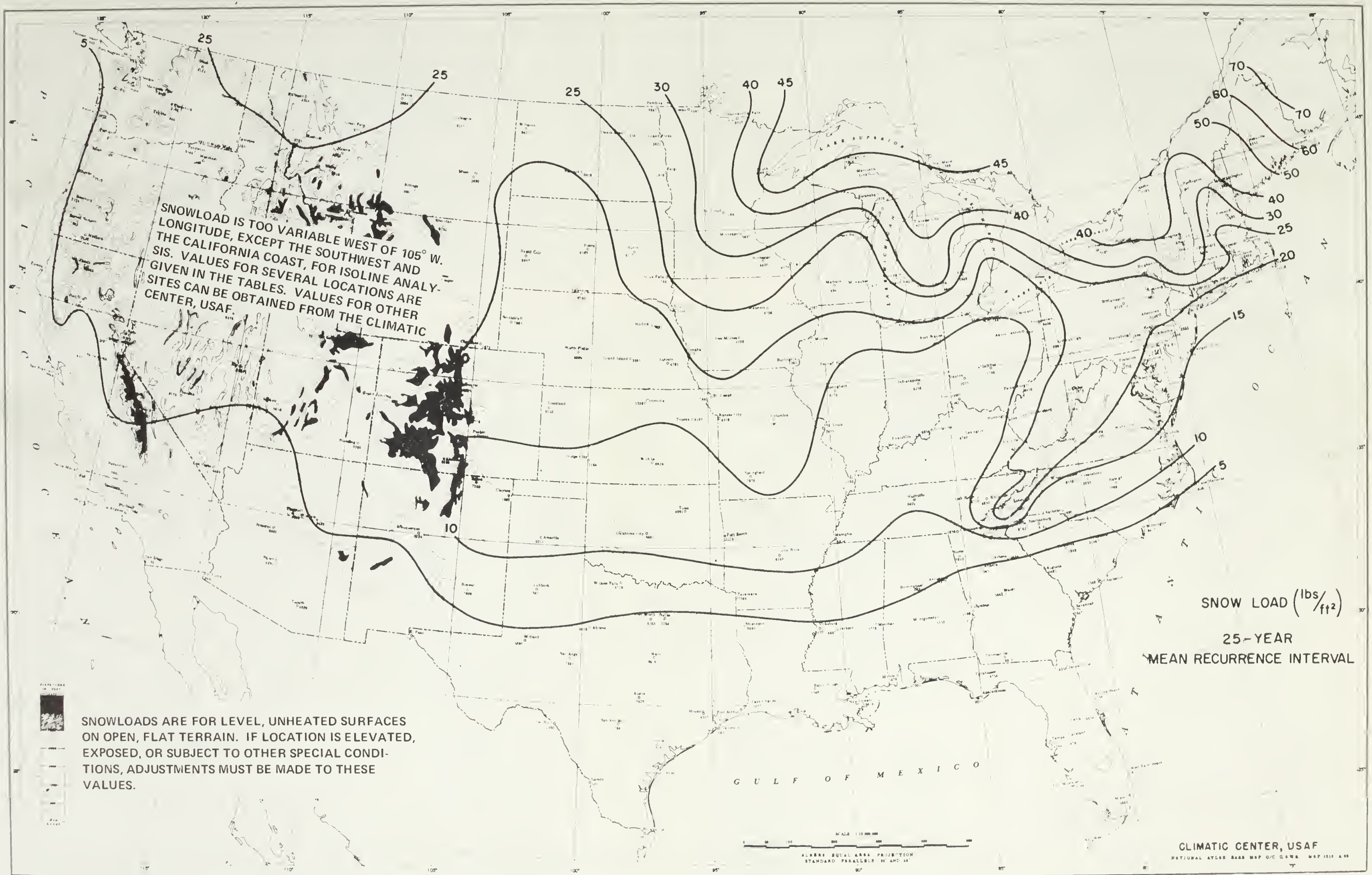


FIGURE 1-1
Snow Loadings in Contiguous States

TABLE 1-5

Wind, Snow, Frost, and Earthquake Data for Contiguous States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Seasonal snowpack (psf)	Frost penetration (inches)	Earthquake zone
ALABAMA:					
Brookley AFB, Mobile	105	121	5	6	0
Maxwell AFB, Montgomery	79	91	5	9	0
Mobile	105	121	5	6	0
Montgomery	79	91	5	6	0
ARIZONA:					
Davis Monthan AFB Tucson	66	76	5	5	2
Luke AFB, Phoenix	79	91	5	7	1
Williams AFB, Phoenix	68	78	5	7	2
Phoenix	70	81	7	7	2
ARKANSAS:					
Little Rock AFB Little Rock	78	90	15	12	1
CALIFORNIA:					
Castle AFB, Merced	53	61	5	5	2
Hamilton AFB, San Francisco	73	84	5	5	3
March AFB, Riverside	51	59	5	5	3
Mather AFB, Sacramento	88	101	5	5	2
Travis AFB, Fairfield	64	74	5	5	3
Vandenberg AFB, Lompoc	63	72	5	5	3
San Diego	56	64	0	0	3
Pasadena	63	72	0	0	3
Long Beach	63	72	0	0	3
San Francisco	74	85	5	5	3
Oakland	74	85	5	5	3
Mare Island	73	84	5	5	3
Sacramento	93	107	5	5	2
Stockton	80	92	5	5	2
China Lake	60	70	5	5	3
COLORADO:					
Lowry AFB, Denver	61	70	20	60	0
Denver	61	70	20	60	0
CONNECTICUT:					
New London	70	81	20	35	2
New Haven	70	81	20	35	1
DELAWARE:					
Dover AFB, Dover	81	93	20	20	1
Lewes	100	115			1
FLORIDA:					
Eglin AFB, Valparaiso	110	127	5	5	0
Homestead AFB, Homestead	109	127	0	0	0
McDill AFB, Tampa	79	91	0	2	0
Patrick AFB, Cocoa	109	125	5	2	0
Jacksonville	90	104	5	2	0
Miami	109	125	0	0	0
Key West	106	122	0	0	0
Pensacola	110	127	5	2	0
Tampa	76	87	0	2	0
GEORGIA:					
Hunter AFB, Savannah	90	104	5	5	2
Robins AFB, Warner Robins	68	78	5	5	1
Turner AFB, Albany	72	83	5	5	0
Augusta	72	83	5	5	1
Atlanta	75	86	5	7	1
Savannah	90	104	5	3	2
Macon	74	85	5	5	1

TABLE 1-5 (Continued)
Wind, Snow, Frost, and Earthquake Data for Contiguous States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Seasonal snowpack (psf)	Frost penetration (inches)	Earthquake zone
IDAHO:					
Mountain Home AFB					
Mountain Home	72	83	20	40	1
ILLINOIS:					
Chanute AFB, Rantoul	81	93	15	35	1
Scott AFB, Belleville	71	82	15	35	1
Chicago	72	83	20	40	1
INDIANA:					
Fort Wayne	77	88	15	40	1
Indianapolis	90	104	15	30	1
IOWA:					
Sioux City	89	102	20	54	1
KANSAS:					
Forbes AFB, Topeka	94	108	15	30	1
Schilling AFB, Salina	89	102	15	24	1
KENTUCKY:					
Lexington	79	91	10	18	1
Louisville	79	91	10	18	1
LOUISIANA:					
Barksdale AFB, Shreveport	58	67	5	5	0
Chennault AFB, Lake Charles	105	121	5	4	0
New Orleans	105	121	5	2	0
MAINE:					
Dow AFB, Bangor	85	98	60	75	2
Loring AFB, Caribou	80	92	75	75	1
Portland	86	99	40	65	2
Bangor	85	98	60	72	2
MARYLAND:					
Andrews AFB					
Washington, D.C.	76	87	20	25	1
Baltimore	78	90	20	22	1
Lexington Park	90	104	20	22	1
MASSACHUSETTS:					
L. G. Hanscom Field					
Boston	94	108	25	50	2
Otis AFB, Cape Cod	105	121	20	50	2
Westover AFB, Springfield	75	86	30	70	2
Boston	94	108	25	50	2
Springfield	75	86	30	70	2
MICHIGAN:					
Kinchelow AFB					
Sault Ste. Marie	84	97	45	65	1
Selfridge AFB, Detroit	69	79	20	50	1
Detroit	66	76	20	50	1
MINNESOTA:					
Minn-St. Paul IAP	78	90	35	75	0
Minneapolis	78	90	35	75	0
Duluth	85	98	50	75	0
MISSISSIPPI:					
Jackson	90	104	5	3	0
Meridan	90	104	5	5	0
Gulfport	110	127	0	5	0
MISSOURI:					
Kansas City	85	98	15	28	1
St. Louis	70	81	15	27	1
MONTANA:					
Malmstrom AFB, Great Falls	72	83	25	75	3

TABLE 1-5 (Continued)
Wind, Snow, Frost, and Earthquake Data for Contiguous States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Seasonal snowpack (psf)	Frost penetration (inches)	Earthquake zone
NEBRASKA:					
Offutt AFB, Omaha	84	97	25	55	1
Omaha	84	97	25	55	1
Hastings	90	104	20	53	1
NEVADA:					
Nellis AFB, Las Vegas	78	90	5	8	1
Stead AFB, Reno	80	92	25	23	3
Fallon	80	92	25	12	3
Hawthorne	80	92	25	30	3
Reno	83	95	25	23	3
NEW HAMPSHIRE:					
Pease AFB, Portsmouth	91	105	30	60	2
Portsmouth	90	104	30	60	2
NEW JERSEY:					
McGuire AFB, Trenton	74	85	20	30	1
Atlantic City	86	99	15	20	1
Bayonne	73	84	20	30	1
NEW MEXICO:					
Cannon AFB, Clovis	68	78	10	15	2
Holloman AFB, Alamogordo	70	81	5	20	2
Walker AFB, Roswell	75	86	10	15	2
Albuquerque	86	99	10	17	2
NEW YORK:					
Griffis AFB, Rome	71	82	40	50	1
Plattsburg AFB, Plattsburg	79	91	35	70	2
Stewart AFB, Newburgh	77	88	25	45	1
Buffalo	79	91	30	35	3
Albany	69	79	30	54	2
New York	73	84	20	40	1
Syracuse	71	82	40	56	1
NORTH CAROLINA:					
Pope AFB, Fayetteville	64	74	10	9	1
Charlotte	78	90	10	8	1
Wilmington	115	132	5	5	1
Cape Hatteras	115	132	5	5	1
Cherry Point	100	115	5	5	1
Camp LeJeune	100	115	5	5	1
NORTH DAKOTA:					
Grand Forks AFB Grand Forks	86	99	25	85	0
Minot AFB, Minot	86	99	15	80	0
OHIO:					
Wright-Patterson AFB, Dayton	80	92	15	40	2
Columbus	80	92	15	40	0
Cincinnati	80	92	10	20	1
OKLAHOMA:					
Tinker AFB, Oklahoma City	80	92	10	20	1
OREGON:					
Portland Int. Apt.	100	115	15	6	2
Portland	100	115	15	6	2
PENNSYLVANIA:					
Olmstead AFB, Harrisburg	63	72	20	35	1
Harrisburg	74	85	20	30	1
Pittsburgh	72	83	20	38	1
Philadelphia	70	81	20	30	1

TABLE 1-5 (Continued)

Wind, Snow, Frost, and Earthquake Data for Contiguous States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Seasonal snowpack (psf)	Frost penetration (inches)	Earthquake zone
RHODE ISLAND:					
Providence	99	114	20	45	2
SOUTH CAROLINA:					
Shaw AFB, Myrtle Beach	65	75	5	6	1
Charleston	106	122	5	3	2
SOUTH DAKOTA:					
Ellsworth AFB, Rapid City	92	106	20	55	0
TENNESSEE:					
Sewart AFB, Smyrna	83	95	10	10	1
Memphis	80	92	10	10	3
TEXAS:					
Amarillo AFB, Amarillo	104	120	10	20	2
Bergstrom AFB, Austin	75	86	5	4	0
Biggs AFB, El Paso	80	92	5	6	2
Carswell AFB, Ft. Worth	74	85	5	12	0
Dyess AFB, Abilene	87	100	5	10	0
Ellington AFB, Houston	78	90	5	3	0
Kelley AFB, San Antonio	77	88	5	4	0
Kingsville NAS, Kingsville	91	105	5	4	0
Reese AFB, Lubbock	75	86	10	15	2
Sheppard AFB, Wichita Falls	74	85	10	15	0
Corpus Christi	100	115	5	2	0
El Paso	80	92	5	6	2
Fort Worth	69	79	5	10	0
Galveston	88	101	5	3	0
Houston	80	92	5	3	0
San Antonio	65	75	5	4	0
Amarillo	104	120	10	20	2
UTAH:					
Hill AFB, Ogden	83	93	30	35	2
Salt Lake City	77	88	25	35	2
VERMONT:					
Burlington	79	91	35	72	2
VIRGINIA:					
Langley AFB, Hampton	95	109	15	6	1
Newport News	92	106	15	10	1
Norfolk	92	106	15	10	1
Richmond	77	88	15	14	1
Yorktown	87	100	15	14	1
WASHINGTON:					
Fairchild AFB, Spokane	79	91	25	65	2
Larson AFB, Moses Lake	63	72	25	35	2
McChord AFB, Tacoma	72	83	20	10	3
Bremerton	72	83	20	9	3
Seattle	72	83	20	8	3
Spokane	79	91	20	30	2
Pasco	65	75	30	25	2
Tacoma	72	83	20	8	3
WEST VIRGINIA:					
Charleston	70	81	15	30	1
WISCONSIN:					
Truax Field, Madison	99	114	25	50	1
Milwaukee	97	112	25	54	1
Green Bay	87	100	25	54	0
WYOMING:					
Francis E. Warren AFB Cheyenne	86	99	20	70	0
WASHINGTON, D. C.	80	92	15	20	1

TABLE 1-6

Wind, Snow, Frost, and Earthquake Data for Locations Outside the United States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Roof snow load (psf)	Frost penetration (inches)	Earthquake zone
AFRICA:					
Libya:					
Wheelus AB	73	84	0	0	2
Morocco:					
Casablanca	73	84	0	0	1
Port Lyautey NAS	73	84	0	0	1
ASIA:					
India:					
Bombay	74	85	0	0	See Note 1
Calcutta	92	106	0	0	See Note 1
Madras	75	86	0	0	See Note 1
New Delhi	74	85	0	0	See Note 1
Japan:					
Itazuke AB	80	92	10	6	3
Johnson AB	90	104	10	6	See Note 2
Misawa AB	82	94	20	18	3
Tachikawa AB	85	98	10	6	See Note 2
Tokyo	85	98	10	6	See Note 2
Wakkanai	100	115	55	36	3
Korea:					
Kimpo AB	63	72	20	30	0
Seoul	63	72	20	30	0
Uijongbu	51	59	15	36	0
Pakistan:					
Peshawar	71	82	10	6	2
Saudi Arabia:					
Bahrain Island	70	81	0	0	See Note 1
Dhahran AB	70	81	0	0	See Note 1
Taiwan:					
Tainan	104	120	0	0	3
Taipei	113	130	0	0	3
Thailand:					
Chiang Mai	68	78	0	0	
Bangkok	68	78	0	0	See Note 1
Sattahip	74	85	0	0	
Udonthani	55	63			
Turkey:					
Ankara	80	92	20	24	2
Karamursel	91	105	15	12	3
Viet Nam:					
Da Nang	104	120			
Nha Trang	82	94			
Saigon	82	94	0	0	See Note 1
ATLANTIC OCEAN AREA:					
Ascension Island	54	62	0	0	See Note 1
Azores:					
Lajes Field	102	117	0	0	2
Bermuda:					
Bermuda NAS	96	110	0	0	1
Kindley AFB	110	127	0	0	1
CARIBBEAN SEA:					
Bahama Islands:					
Eleuthera Island	120	138	0	0	1
Grand Bahama Island	120	138	0	0	1
Great Exuma Island	120	138	0	0	1

TABLE 1-6 (Continued)
Wind, Snow, Frost, and Earthquake Data for Locations Outside the United States

Location	Wind, peak gust velocity		Roof snow load (psf)	Frost penetration (inches)	Earthquake zone
	(knots)	(mph)			
CARIBBEAN SEA–Continued					
Cuba:					
Guantanamo NAS	78	90	0	0	2
Leeward Islands:					
Antigua Island	120	138	0	0	3
Puerto Rico:					
Raney AFB	81	93	0	0	3
San Juan	101	116	0	0	3
Vieques Island	120	138	0	0	3
Trinidad Island:					
Port of Spain	48	55	0	0	2
Trinidad NS	48	55	0	0	2
CENTRAL AMERICA:					
Canal Zone:					
Albrook AFB	54	62	0	0	2
Balboa	54	62	0	0	2
Coco Solo	45	52	0	0	2
Colon	50	58	0	0	2
Cristobal	50	58	0	0	2
France AFB	50	58	0	0	2
EUROPE:					
England:					
Birmingham	72	83	15	12	See Note 1
London	77	88	15	12	See Note 1
Mildenhall AB	84	97	15	12	See Note 1
Plymouth	76	87	10	12	See Note 1
Sculthorpe AB	80	92	15	12	See Note 1
Southport	84	97	10	12	See Note 1
South Shields	80	92	15	12	See Note 1
Spurn Head	80	92	15	12	See Note 1
France:					
Nancy	70	81	15	18	0
Paris/Le Bourget	82	94	20	18	0
Rennes	89	102	15	18	0
Vichy	99	114	25	24	0
Germany:					
Bremen	69	79	25	30	0
Munich-Riem	79	91	40	36	0
Rhein-Main AB	69	79	25	30	0
Stuttgart AB	73	84	45	36	0
Greece:					
Athens	75	86	5	0	2
Italy:					
Aviano AB	64	74	10	18	2
Brindisi	89	102	5	6	0
Sigonella-Katania	78	90	. . .	. . .	2
Scotland:					
Aberdeen	73	84	15	12	See Note 1
Edinburgh	80	92	15	12	See Note 1
Edzell	73	84	15	12	1
Glasgow Renfrew Airfield	84	97	15	12	1
Lerwick, Shetland Islands	90	104	15	18	See Note 1

TABLE 1-6 (Continued)

Wind, Snow, Frost, and Earthquake Data for Locations Outside the United States

Location	Wind, peak gust velocity (knots)	Wind, peak gust velocity (mph)	Roof snow load (psf)	Frost penetration (inches)	Earthquake zone
EUROPE—Continued					
Londonderry	108	124	15	12	1
Prestwick	81	93	15	12	(1)
Stornoway	97	112	15	12	(1)
Thurso	85	98	15	12	1
Spain:					
Madrid	67	77	10	6	See Note 1
Rota	76	87	5	0	1
San Pablo	95	109	5	6	See Note 1
Zaragoza	95	109	10	6	See Note 1
NORTH AMERICA:					
Alaska:					
Adak, Aleutian Islands	108	124	15	24	3
Anchorage	84	97	35	60	3
Annette	82	94	20	24	See Note 1
Attu	155	178	35	24	3
Barrow	89	109	20	permafrost	1
Bethel	82	94	33	60	1
Cold Bay	96	110	20	36	3
Cordova	82	94	76	48	3
Eielson AFB	65	75	33	60	3
Elmendorf AFB	81	93	35	60	3
Fairbanks	65	75	35	60	3
Gambell	113	130	25	48	1
Juneau	80	92	42	36	2
King Salmon	100	115	12	60	3
Kodiak	101	116	17	48	3
Kotzebue	106	122	20	permafrost	1
McGrath	74	85	50	84	2
Middleton Island AFS	109	125	47	48	3
Nikolski, Umnak Island	112	129	25	36	3
Nome	104	120	43	permafrost	1
Northeast Cape AFS St. Lawrence Island	116	133	26	48	1
Shemya Island	155	178	34	24	3
St. Paul Island	91	105	24	36	1
Umiat	97	112	30	permafrost	1
Wales	91	105	50	permafrost	1
Yakutat	86	99	108	36	3
Canada:					
Argentia NAS, Newfoundland	93	107	47	36	2
Churchill, Manitoba	87	100	66	permafrost	0
Cold Lake, Alberta	65	75	41	72	1
Edmonton, Alberta	68	78	27	60	1
E. Harmon AFB, Newfoundland	91	105	86	60	2
Fort William, Ontario	65	75	73	60	0
Frobisher, N.W.T.	87	100	50	permafrost	0
Goose Airport, Newfoundland	72	83	100	60	0
Ottawa, Ontario	73	84	60	48	2
St. John's, Newfoundland	92	106	72	36	2
Toronto, Ontario	73	84	40	36	1
Winnipeg, Manitoba	66	76	45	60	1
Greenland:					
Narsarssuak AB	112	129	30	60	1
Simiutak AB	134	154	25	60	1
Sondrestrom AB	97	112	20	permafrost	1

TABLE 1-6 (Continued)
Wind, Snow, Frost, and Earthquake Data for Locations Outside the United States

Location	Wind, peak gust velocity		Roof snow load (psf)	Frost penetration (inches)	Earthquake zone
	(knots)	(mph)			
NORTH AMERICA—Continued					
Thule AB	115	132	25	permafrost	1
Iceland:					
Keflavik	100	115	30	24	3
Thorshofn	118	136	30	36	See Note 1
PACIFIC OCEAN AREA:					
Caroline Islands:					
Koror, Palau Islands	83	95	0	0	2
Ponape	95	109	0	0	0
Hawaii:					
Barber's Point	58	67	0	0	1
Hickam AFB	69	79	0	0	1
Kaneohe Bay	73	84	0	0	1
Wheeler AFB	55	63	0	0	1
Hawaiian Islands:					
Hawaii			0	0	3
Kahoolawe			0	0	2
Kavai			0	0	0
Lanai			0	0	2
Maui			0	0	2
Molokai			0	0	2
Nihau			0	0	0
Oahu			0	0	1
Johnston Island	63	72	0	0	1
Mariana Islands:					
Agana, Guam	135	155	0	0	3
Andersen AFB, Guam	135	155	0	0	3
Kwajalein	90	104	0	0	1
Saipan	130	150	0	0	3
Tinian	130	150	0	0	3
Marcus Island	130	150	0	0	1
Midway Island	76	87	0	0	See Note 1
Okinawa:					
Kadena AB	160	184	0	0	3
Naha AB	155	178	0	0	3
Philippine Islands:					
Clark AFB	76	87	0	0	3
Sangley Point	59	68	0	0	3
Subic Bay	67	77	0	0	3
Samoa Islands:					
Apia, Upolu Island	128	147	0	0	3
Tutuila, Tutuila Island	128	147	0	0	3
Volcano Islands:					
Iwo Jima AB	180	206	0	0	(1)
Wake Island	75	86	0	0	0

[1] Not available.
[2] Use local building code.

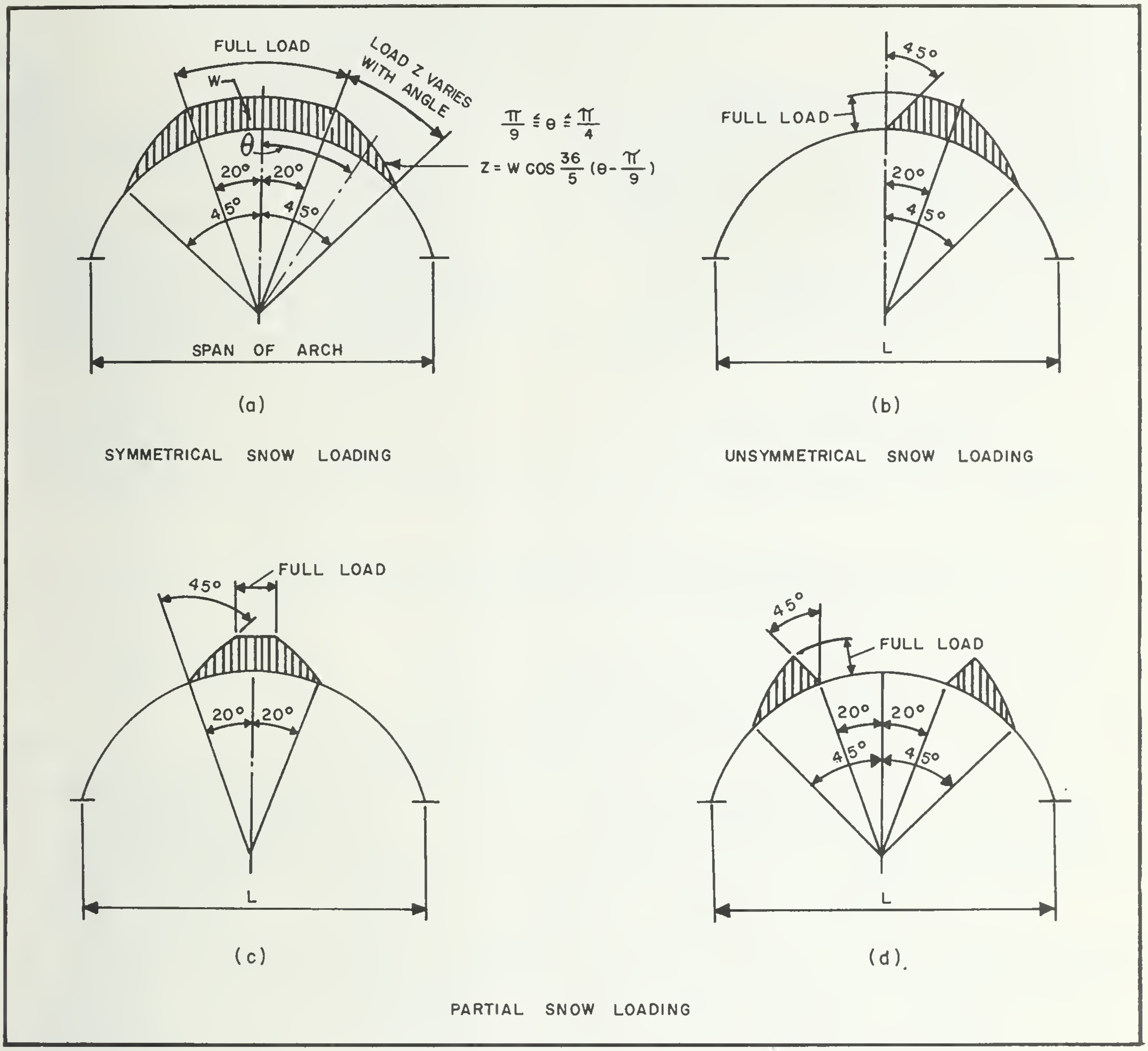


FIGURE 1-2
Snow Load on Arches

Member	*Increase (%)*
Beams	100
Columns	80
Foundations, footings, and piers	40

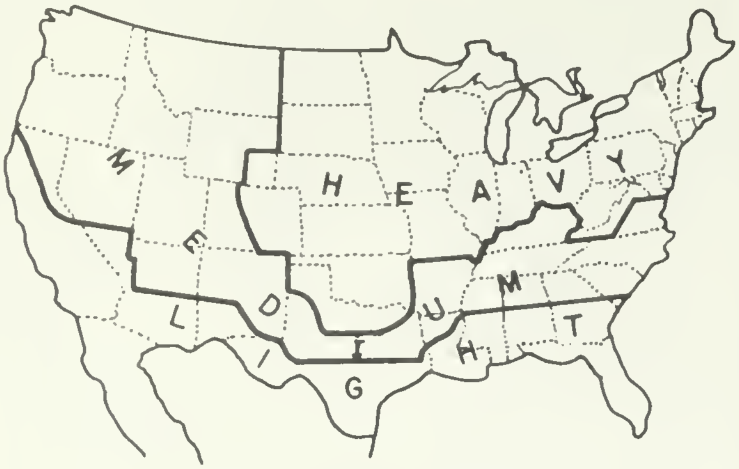
b. Machinery. For reciprocating machinery or heavy power-driven units, increase loads a minimum of 50 percent. For light shaft or motor-driven machinery, increase loads a minimum of 25 percent.

c. Crane Runways and Supports. Percentages of increase for impact on crane runways and supports are listed in Table 1-7.

d. Highway Loadings. Highway loadings are listed in the AASHO Standards.

e. Railway Loadings. Proper railway loadings are specified in the AREA Manual.

f. Escalators. Add 15 percent to total of dead plus live load.



(a) GEOGRAPHIC DISTRIBUTION

LOADING DISTRICT	RADIAL THICKNESS OF ICE (In)
HEAVY	0.50
MEDIUM	0.25
LIGHT	NONE

(b) THICKNESS OF ICE COVERING

FIGURE 1-3

Ice Load on Antenna Supports and Transmission Line Structures

TABLE 1-7

Crane Runways and Supports, Load Increases for Impact

Capacity of hook load (short tons)	Load increase expressed as percent of maximum crane reaction							
	Speeds 200 fpm or less				Speeds exceeding 200 fpm			
	Overhead traveling crane, traveling wall crane		Fixed revolving cranes	Traveling revolving cranes	Overhead traveling crane, traveling wall crane		Fixed revolving cranes	Traveling revolving cranes
	Runway girders	Columns	Towers	Docks, piers, tracks	Runway girders	Columns	Towers	Docks, piers, tracks
25 or less	15	12	15	12	18	14	18	15
26 to 50	13	10	13	10	15	10	15	12
51 to 80	10	9	10	8	12	12	12	10
81 to 120	9	7	9	6	10	8	10	8
121 to 180	8	6	8	6	9	7	9	8
Over 180	6	5	6	6	8	6	8	8

9. VIBRATIONS. Vibrations are induced in structures by reciprocating and rotating equipment, rapid application and subsequent removal of a load, or by other means. Vibrations take place in flexural, extensional, or torsional modes, or any combination of the three.

a. Resonance. Resonance will occur when the frequency of an applied dynamic load coincides with a natural frequency of the supporting structure. In this condition, vibration deflections increase progressively to dangerous proportions. Prevent resonance by insuring in design that the natural frequency of a structure and the frequency of load application do not coincide.

b. Collateral Reading. For further information on the solutions of vibratory stresses and deflections,

see *Soil Mechanics, Foundations, and Earth Structures*, NAVFAC DM-7, and Chapter 9, Section 9 of this manual. Also refer to *Vibration Problems in Engineering* and *Dynamics of Framed Structures* (See Bibliography).

Section 4. WIND LOADS

1. EXTERNAL PRESSURE. Buildings or other structures shall be designed to withstand applicable external wind pressure.

a. Velocity Pressure. Velocity pressure (q) is determined by:

$$q = \frac{1}{2} \rho V^2 C_h = \text{velocity pressure (air at } 15^\circ \text{ C temperature -- sea level)}$$

$$q = \frac{1}{2} \times \frac{0.0765}{32.2} \times \left(\frac{5280}{3600}\right) V^2 \times C_h \qquad (1\text{-}3)$$

$$q = 0.00256\, V^2 C_h,$$

where

q = velocity pressure of wind (psf),
C_h = height correction factor,
V = wind velocity (mph), and
ρ = density of air.

(1) Wind Velocity. Peak gust wind speeds are given for the contiguous United States in Figure 1-4 and Table 1-5, and for locations outside the States in Table 1-6. Use a minimum of 80 miles per hour wind velocity for design. For locations subject to hurricanes, typhoons, or other winds in excess to 90 miles per hour, Chapter 9, Section 9 provides additional criteria and recommendations for design.

(2) Gust Factors. Gust factors are incorporated in the peak gust wind speeds given in Figure 1-4 and Tables 1-5 and 1-6. Use of the peak gust speed eliminates the need for estimation of the gust factor. The gust factor is variable, dependent on the general wind speed level at the particular location. The peak gust velocity indicated is assumed to be sustained for an interval of 2 to 3 seconds, and therefore will ordinarily be treated as a steady wind because the natural response period of most structures is less than 1.5 seconds. When the response period of the structure exceeds 1.5 seconds, appropriate methods of analyses for dynamic forces shall be used.

(3) Correction Coefficient for Height. Use curve A of Figure 1-5 or Equation 1-4 to obtain the correction coefficient for velocity pressures above 30 feet. The correction factor, C_h, below 30 feet is equal to 1.0. The correction factor above 30 feet is:

$$C_h = \left(\frac{h}{30}\right)^{2/7}, \qquad (1\text{-}4)$$

for h = 100 feet

$$C_h = \left(\frac{100}{30}\right)^{2/7} = 1.41.$$

For towers 300 feet and higher refer to Chapter 9.

b. Wind Pressure. The design wind pressure for buildings and other structures shall be determined by the applicable velocity pressure q, (obtained in accordance with Equation 1-3 or Figure 1-5) multiplied by the appropriate shape (Figure 1-12), or pressure coefficients (Figures 1-6 through 1-11).

2. MAIN FRAMES, TRUSSES, AND OTHER MAIN MEMBERS. Design main frames, trusses, and other main members for the external pressure ($p = q \times C$) where C is the shape coefficient.

3. PURLINS, GIRTS, SHEATHING, SIDING, AND FASTENINGS. The maximum loading for purlins, girts, sheathing, siding, and fastenings shall be obtained from the following combinations of loads and shall be used as the design load:

(1) External pressure (p) and internal pressure of 0.6q acting outward as a bursting force.

(2) External pressure (p) and internal pressure of 0.4q acting inward as an internal suction. In the above loading combinations, the internal pressures are assumed to be uniformly distributed over the interior surface of the building.

4. BRACING. Wall and roof bracing shall be designed in accordance with the applicable provisions of Paragraphs 2 and 3 of this section and Chapter 9. Bracing shall be located so that lateral forces will be transmitted as directly as possible to the foundation. Bracing should assist the decking or roofing in diaphragm action, and should be adequate to prevent buckling of compression members, such as

columns and compression chords of trusses. Specific requirements follow.

a. Structural Integrity. To insure structural integrity of the building and to provide for structural interaction between walls and roof, bracing shall be designed to transmit wall reactions (at the plane of the roof) to the foundation. In addition, buildings shall be designed as a unit; where diaphragm action exists, it shall be taken into account. Proper anchorage shall be provided between horizontal diaphragms and endwalls. The wall reactions shall be based on the pressure (p); the shape factor (c) for sidewalls and roof, as given in Figures 1-6 through 1-11; the shape factor (c) for endwalls equal to +0.9 and for roof equal to –0.7 with wind normal to the endwall; and internal pressures of 0.6q acting outward as a bursting force, or 0.4q acting inward as an internal suction. The external loadings (p) and internal loadings (+0.6 and/or –0.4q) shall be combined for maximum loading of members.

b. Column Action. For members subjected to the combination of loads listed in Section 8, beam column action of compression members shall be investigated.

5. EAVES AND CORNICES. Overhanging eaves and cornices shall be designed for an upward pressure of twice the extèrnal pressure (p).

6. BRIDGE STRUCTURES. Criteria on wind loads and their effect on bridge structures are contained in the AASHO Standards and the AREA Manual.

7. SHIPS. Considerations for wind forces on ships are outlined in *Waterfront Operational Facilities*, NAVFAC DM-25, and *Harbor and Coastal Facilities*, NAVFAC DM-26.

8. TANKS, TOWERS, STACKS AND SIMILAR STRUCTURES.

a. On-Support Structures. Modify wind pressure in accordance with the shape coefficients given in Figure 1-12.

b. Drag Sensitivity. In general, tanks, towers, and stacks are drag-sensitive structures. Consequently, in the design of such structures, the effects of wind-induced vibration shall be investigated.

c. Collateral Reading. For further information, see *Wind-Induced Vibrations in Antenna Members*, ASCE (see Bibliography).

9. EXTERIOR BEAMS AND GIRDERS. The circular cross section is more vulnerable to vortex-shedding phenomenon than other structural shapes. However, failure of standard types of structural members has been attributed to wind-induced vibrations. Little information is available on vibrations in members of I and WF shapes. However, to avoid vortex-shedding phenomenon, rectangular beams and girders should have a width-to-depth ratio of less than 0.75 or greater than 3.5.

10. CRANES AND DERRICKS. For nonoperating conditions, design cranes and derricks for external wind pressures as determined above. For criteria for operating conditions, see *Weight Handling Equipment and Service Craft*, NAVDOCKS DM-38.

11. GUY WIRES AND CABLES. Use the coefficients from the curves in Figure 1-13 to compute the total wind forces on guy wires or cables. The wind direction is assumed to be parallel to the Y direction in the sketch. An inclined plane, determined by the wind direction vector and the guy chord, contains the lift and drag forces. The drag is assumed to act in the direction of the wind, and the lift is assumed to act normal to the drag. For ease of making calculations, the lift force usually is broken into horizontal and vertical components; that is, horizontal component of lift = lift cos ρ; vertical component of lift = lift sin ρ. For additional information, see *Engineering Aerodynamics* (See Bibliography).

Section 5. EARTHQUAKE LOADS

1. CRITERIA SOURCE. Criteria and guidance for the design of buildings in seismic areas shall be in accordance with *Triservice Engineer Manual for Seismic Design for Buildings*, NAVDOCKS P-355.

2. EARTHQUAKE ZONES. Earthquake zones are contained in NAVDOCKS P355.

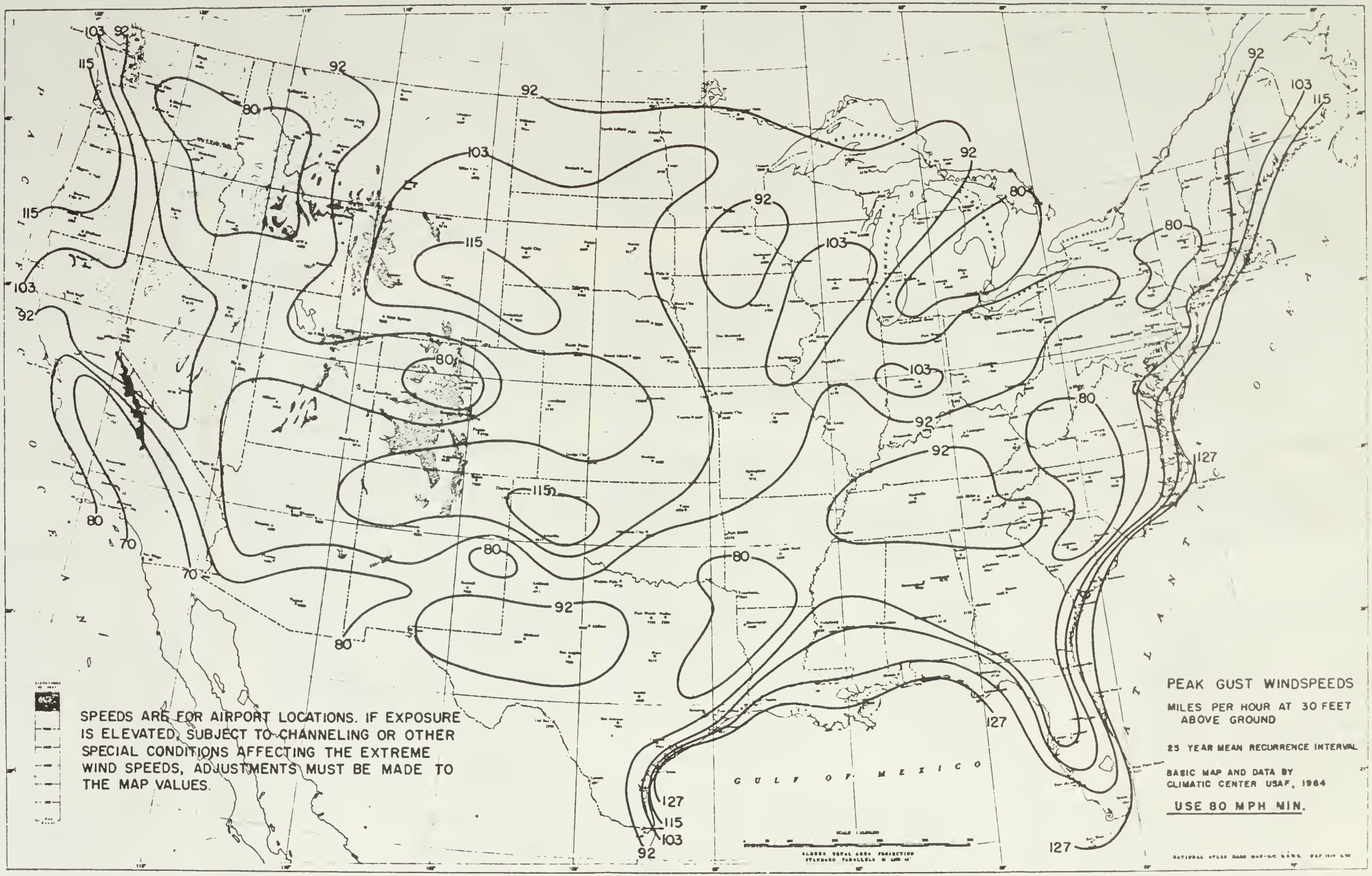


FIGURE 1-4
Peak Gust Windspeeds (mph) at 30 Feet Above Ground
(25-Year Recurrence Interval)

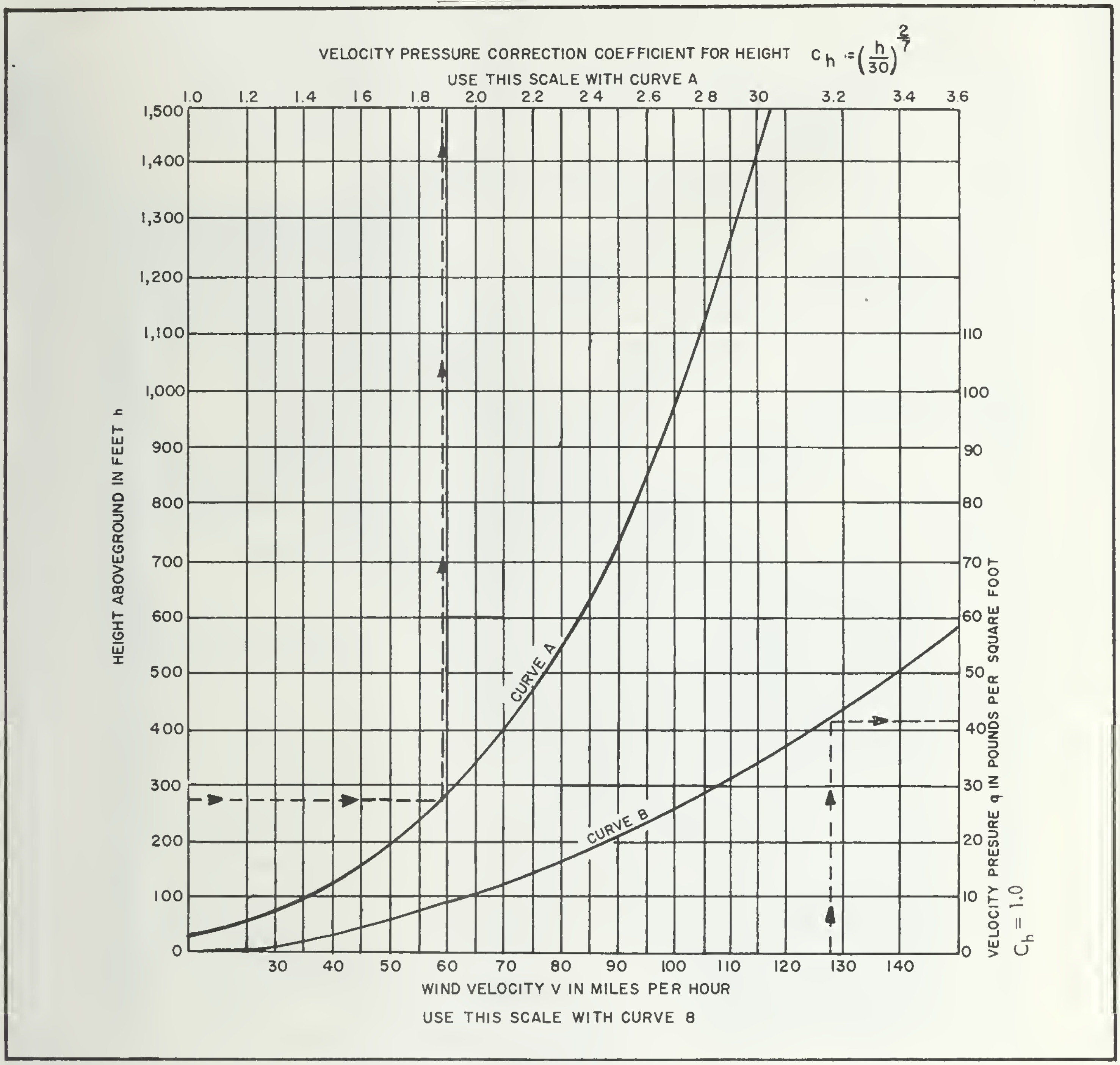
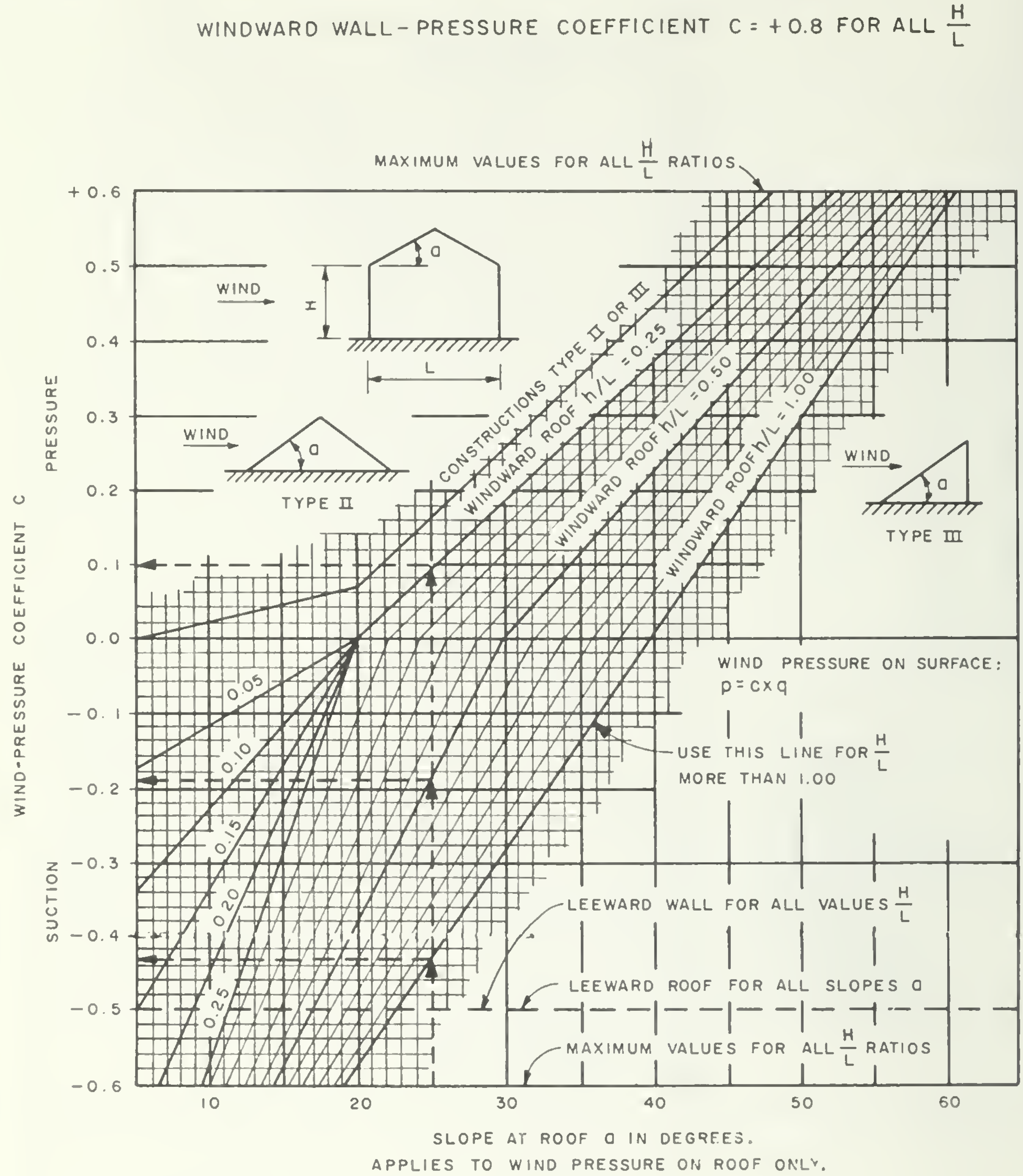


FIGURE 1-5
Velocity Pressure and Variation of Velocity Pressure with Height Aboveground



NOTE: See Figure 1-9 for Open Shed construction.

FIGURE 1-6
Externol Wind-Pressure Coefficients for Goble-Type Building

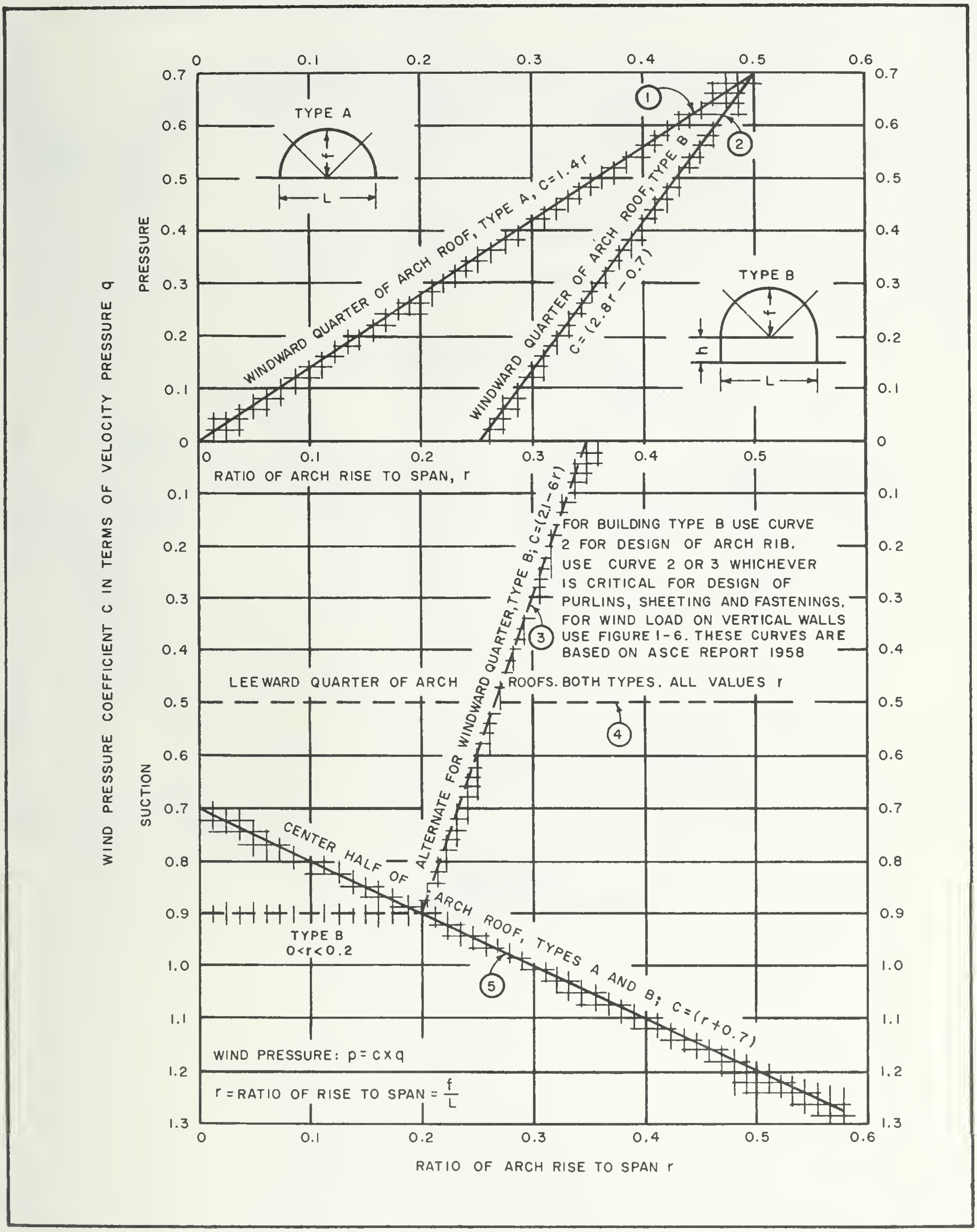


FIGURE 1-7
External Wind-Pressure Coefficients for Rounded Roofs

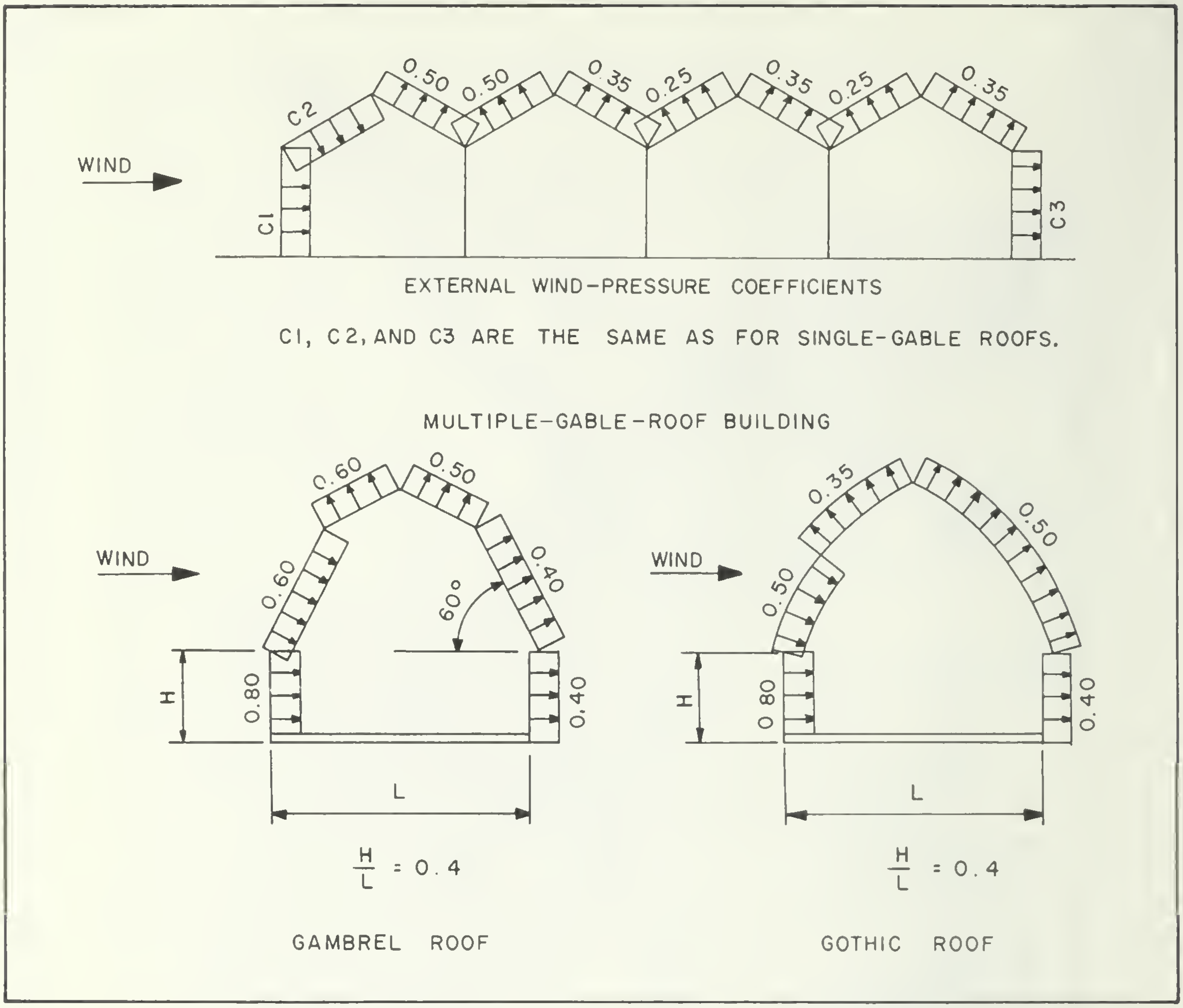


FIGURE 1-8
Wind-Pressure Coefficients

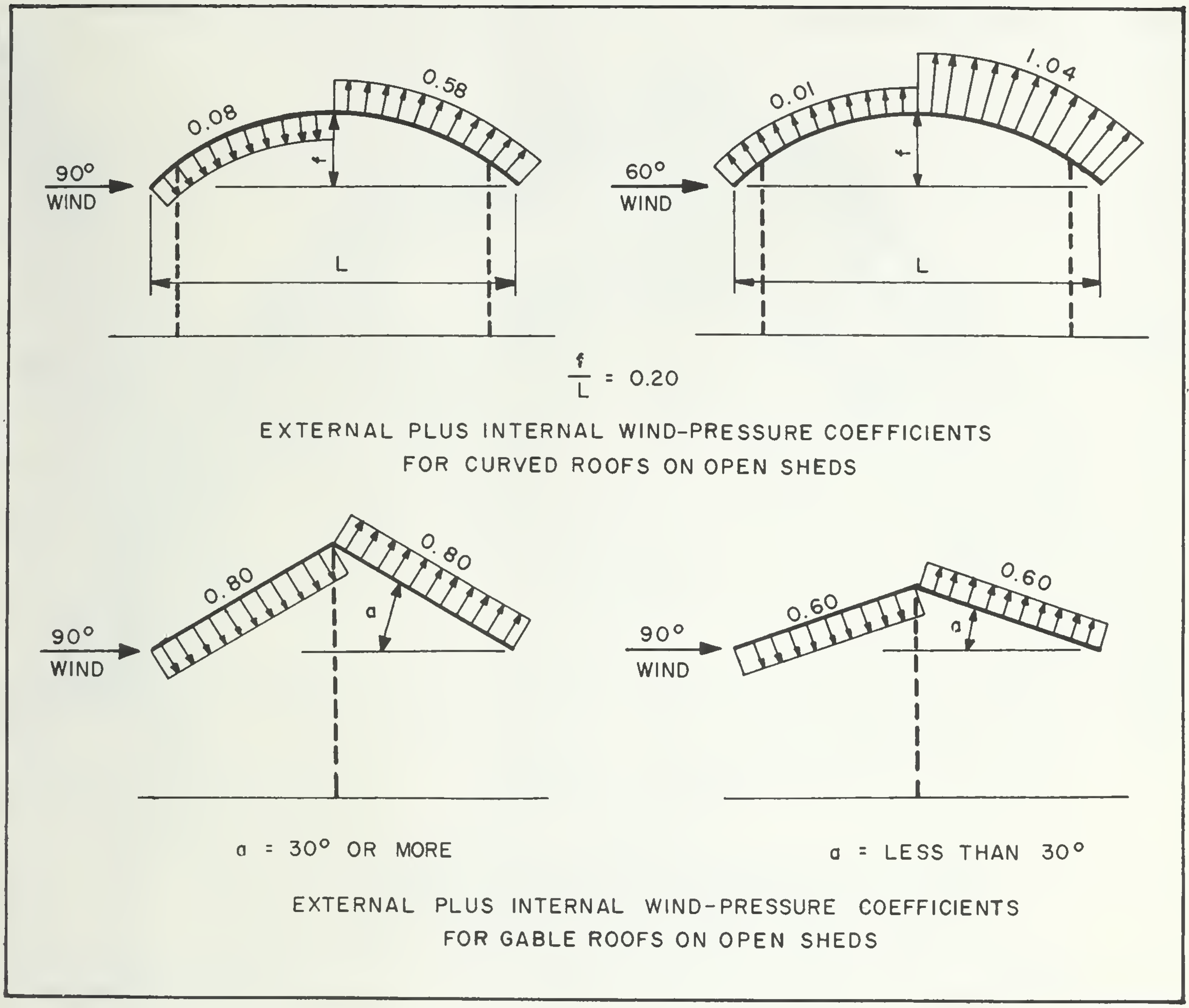


FIGURE 1-9
Wind-Pressure Coefficients for Open Sheds

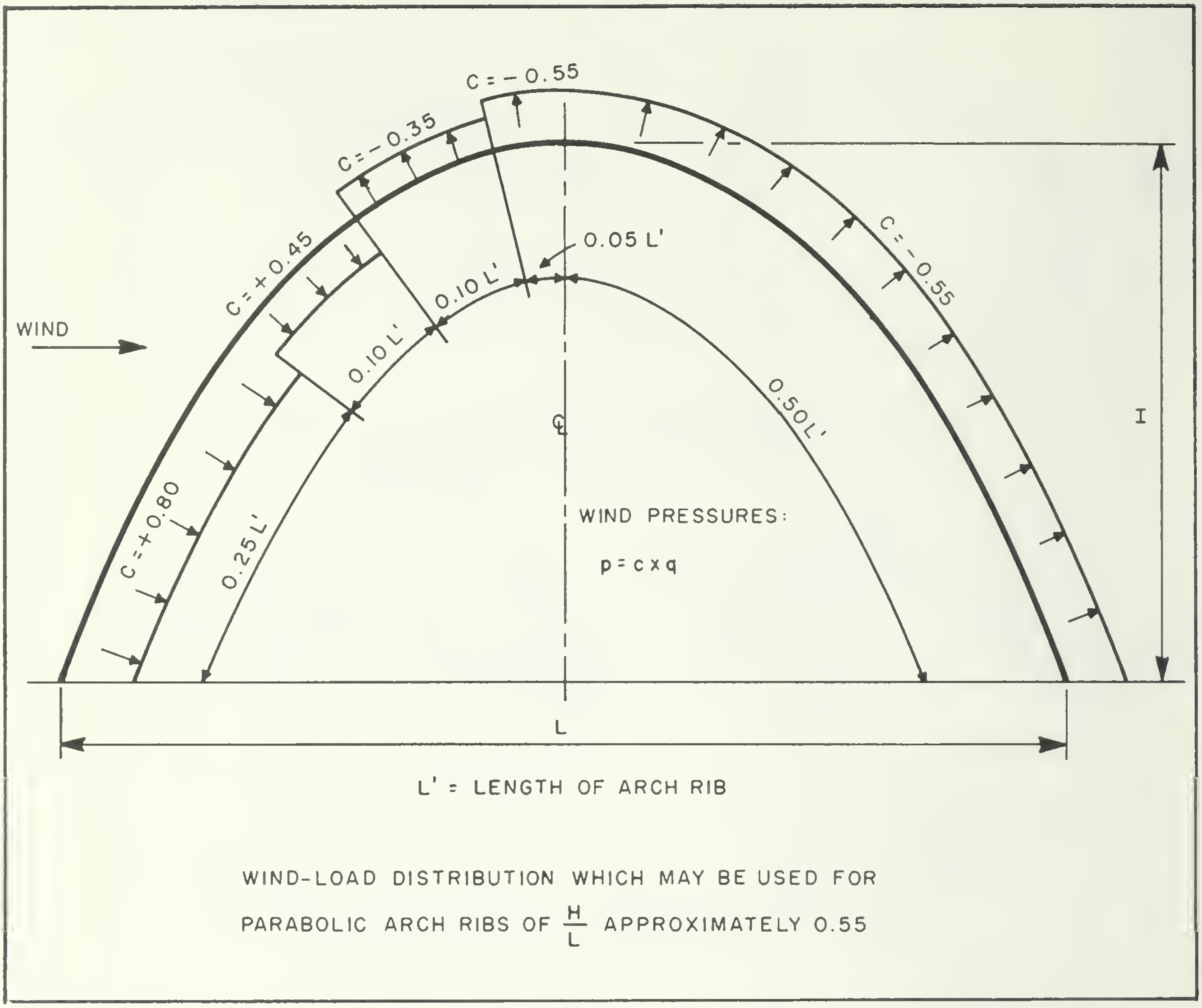


FIGURE 1-10
Wind-Pressure Coefficients for Arch Without Monitor

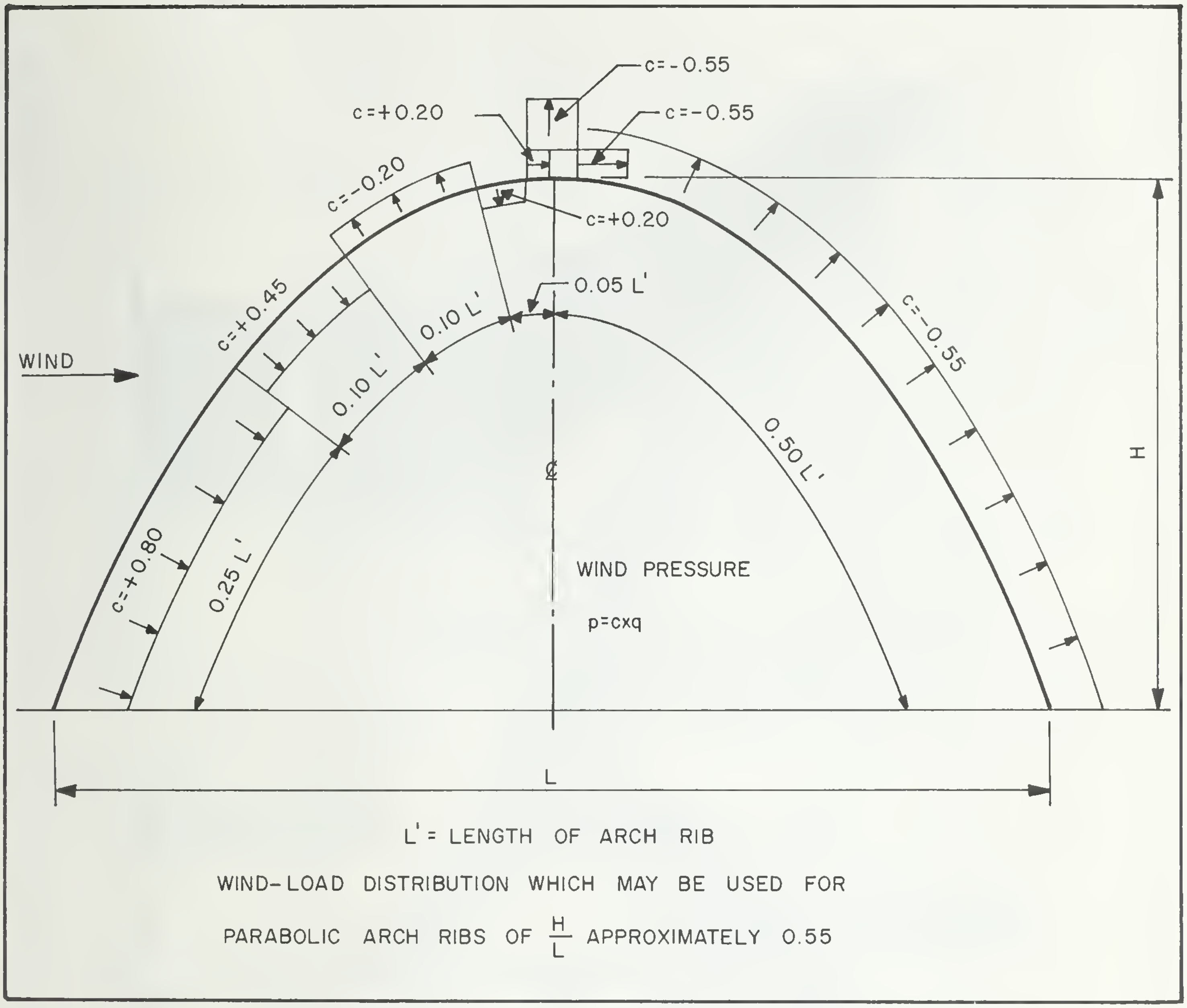
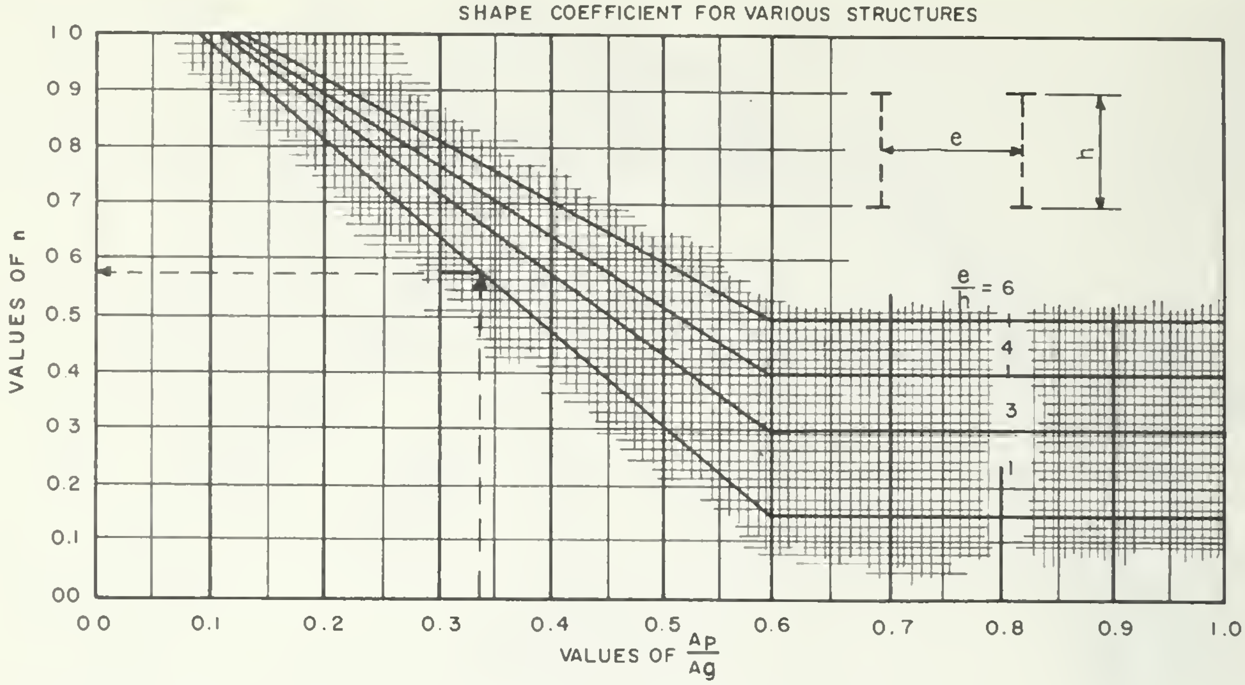


FIGURE 1-11
Wind-Pressure Coefficients for Arch With Monitor



Ap= TOTAL PROJECTED AREA OF MEMBERS ON ONE SIDE OF THE STRUCTURE.

Ag= TOTAL AREA WITHIN THE LIMITING LINES FOR ONE SIDE OF THE STRUCTURE.

P= TOTAL WIND LOAD ON THE STRUCTURE. $P = S x_g x A_p$

n IN THE DIAGRAM APPLIES TO TRUSSES AND LATTICED MEMBERS EXCEPT TRIANGULAR TOWERS.

S = SHAPE COEFFICIENT

TYPE OF STRUCTURES	SHAPE COEFFICIENT ON PROJECTED AREA S
DOUBLE PARALLEL SOLID GIRDER	1.10
DOUBLE PARALLEL TRUSSES AND DOUBLE PARALLEL LATTICED MEMBERS	1.6 (1 + n)
GIRDERS AND TRUSSES WITH m PARALLEL MEMBERS WHERE m IS MORE THAN 2	1.5 + (m−2) 0.5
SQUARE AND RECTANGULAR CHIMNEYS	1.20
CONICAL, HEMISPHERICAL AND SEMIELLIPTICAL SURFACES	0.60
SIGNBOARDS	1.20
SPHERES	0.40
TOWERS	
SQUARE CROSS SECTION, WIND ON FACE → □	1.6 (1+n)
SQUARE CROSS SECTION, WIND ON CORNER → ◇	1.92 (1+n)
TRIANGULAR CROSS SECTION, WIND ON FACE → ▷	2.28
TRIANGULAR CROSS SECTION, WIND ON CORNER → ◁	1.93

USE 2/3 OF ABOVE VALUES FOR CYLINDRICAL MEMBERS

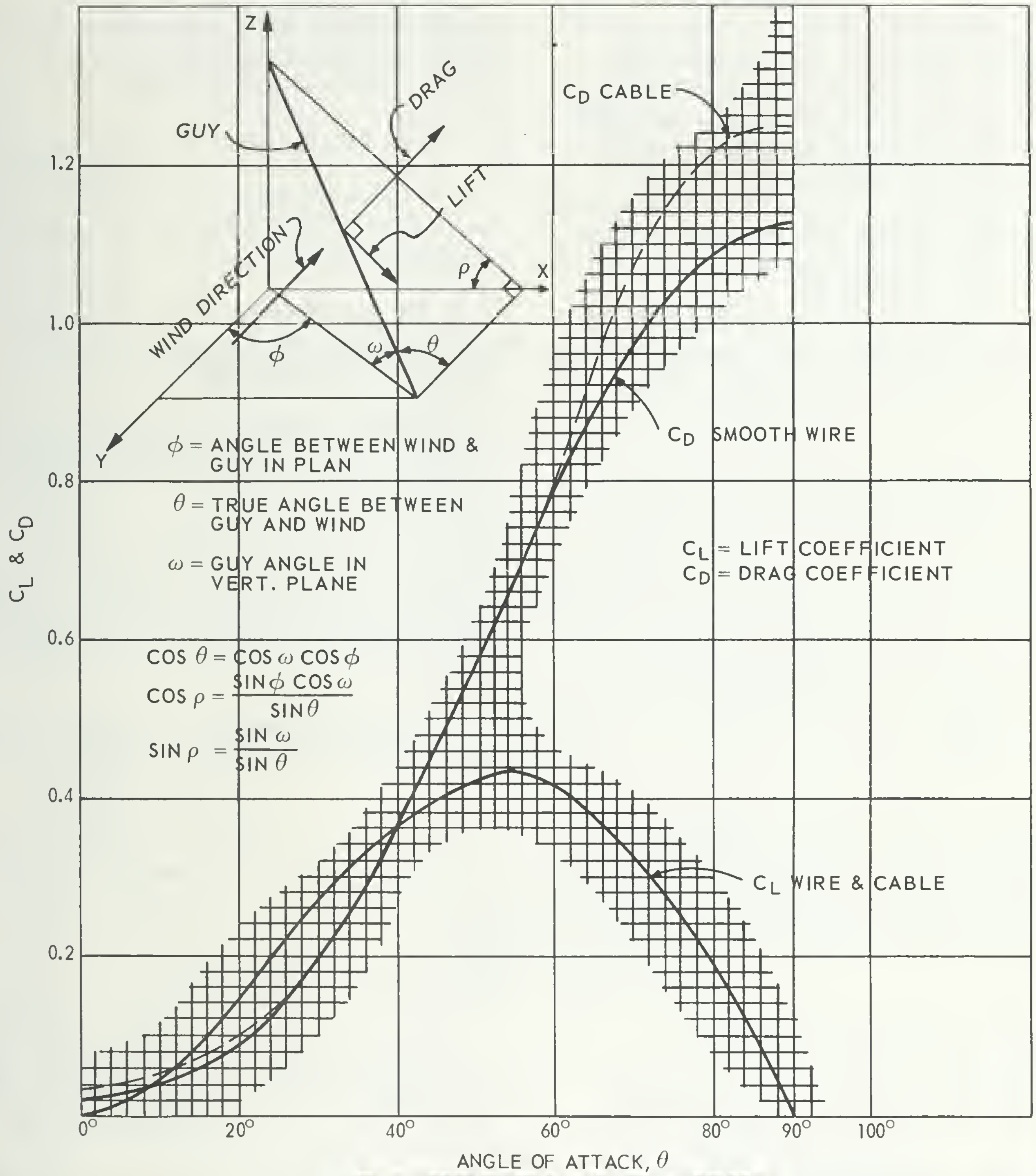
CYLINDRICAL SURFACES

TANKS, RISERPIPES, CHIMNEYS, FLAGPOLES, ANTENNAS AND SIMILAR STRUCTURES

LENGTH / DIAMETER	1	2	3	10	20	40	∞
S	0 63	0 69	0 75	0 83	0 92	1.00	1 20

FIGURE 1-12

Shape Coefficients for Miscellaneous Structures



Drag and Lift Coefficients for Wire and Cable

DRAG & LIFT FORCES

DRAG = $2.133\ (c\ d\ v^2)\ C_D \times 10^{-7}$ Kips

LIFT = $2.133\ (c\ d\ v^2)\ C_L \times 10^{-7}$ Kips

where c = chord length of cable in feet

d = diameter of cable in inches

v = wind velocity in mph (usually taken as velocity at mid-height of cable)

Note: LIFT for leeward cable is positive acting upward.

FIGURE 1-13
Wind Forces on Guy Wires and Cables

Section 6. OTHER LOADS

1. EARTH PRESSURES AND FOUNDATION STRUCTURE LOADS. Standards for determining earth pressures and foundation structure loads are contained in *Soil Mechanics, Foundations, and Earth Structures*, NAVFAC DM-7.

2. FLUID PRESSURES AND FORCES. Fluid pressures and forces which must be considered in structural design are as follows.

a. Hydrostatic Pressure. Use hydrostatic pressure criteria in *American Civil Engineering Practice*, Vol. II. (See Criteria Sources.)

b. Wave Forces. Wave force criteria are described in *Waterfront Operational Facilities*, NAVFAC DM-25, and *Harbor and Coastal Facilities*, NAVFAC DM-26.

c. Current Forces. Current force criteria are contained in *Waterfront Operational Facilities*, NAVFAC DM-25, and *Harbor and Coastal Facilities*, NAVFAC DM-26.

3. ICE FORCES.

a. Drift Ice. Only indefinite recommendations can be made to protect a structure against drift ice. Consider impact forces and subsequent piling up of ice on the structure; also, consider the increase in current forces due to decreased areas of stream flow.

b. Sheet Ice. An estimate of thickness of sheet ice can be made from site locations.

(1) Small, Yielding Structures. For relatively small, yielding structures, the ice pressure used in design considerations shall be the value required for local crushing (that is, 400 psi).

(2) Large, Unyielding Structures. For relatively large, unyielding structures, the forces of sheet ice to be resisted shall be based on the buckling strength of the ice sheet using a modulus of rupture of 300 psi.

(3) Rounded or Pointed Surfaces. For rounded or pointed surfaces, use two-thirds the values in Paragraphs 3b(1) or 3b(2) immediately preceding.

c. Uplift. The forces of uplift of the ice sheets shall be based on the modulus of rupture of 300 psi.

d. Reducing Ice Forces. Ice forces computed by the above methods are very large and difficult to handle. Consider reducing such forces by use of ice breakers, starlings, sheltering, or other means.

4. CENTRIFUGAL AND TRACTION FORCES.

a. Highway Loadings. Centrifugal and traction forces affecting highway loadings are contained in the AASHO Standards.

b. Railway Loadings. Railway loadings and the effects of centrifugal and traction forces are described in the AREA Manual.

5. THERMAL FORCES. Provide for stresses or movements resulting from variations in temperature. On cable structures, consider changes in cable sag and tension. The rises and falls in temperature shall be determined for the localities in which structures are built. They shall be established from assumed temperatures at times of erection. Consider the lags between air temperatures and interior temperatures of massive concrete members or structures.

a. Temperature Ranges. The ranges of temperature generally shall be:

	Climate (°F)	
Structure	*Moderate*	*Cold*
Metal	0 to 120	-30 to 120
Concrete:		
Rise	30	35
Fall	-40	-45

b. Piping. To accommodate changes in length due to thermal variations, pipes frequently are held at a single point. In vertical piping in buildings, the loads may be severe and shall be included in the design of supporting framing.

6. FRICTION FORCES.

a. Sliding Plates. Use 10 percent of the dead load reactions for bronze or copper-alloy sliding plates. Consult manufacturer for special systems.

b. Rockers or Rollers. Use 3 percent of the dead load reactions when employing rockers or rollers.

c. Foundations on Earth. Criteria for foundations on earth are contained in *Soil Mechanics, Foundations, and Earth Structures*, NAVFAC DM-7.

d. Other Bearings. Use the *Mechanical Engineers Handbook* (see Criteria Sources) for coefficients of friction. Base the forces on dead load reactions plus any applicable longtime live load reactions.

7. SHRINKAGE.

a. Stress. Arches and similar structures shall be investigated for stresses induced by shrinkage and rib shortening.

b. Coefficient of Shrinkage. For masonry structures, the minimum linear coefficient of shrinkage shall be assumed as 0.0002, and the theoretical shrinkage displacement shall be computed as the product of the linear coefficient and the length of the member.

8. FOUNDATION DISPLACEMENT AND SETTLEMENT. Criteria for foundation displacement and settlement are outlined in *Soil Mechanics, Foundations, and Earth Structures,* NAVFAC DM-7.

9. FROST DEPTH. See Figure 1-14 and Tables 1-5 and 1-6. Use minimum of 24 inches except where governed by local conditions.

10. BOMB AND BLAST LOADS. For forces due to bomb impact and blast waves, see Criteria Sources indicated in Chapter 9.

Section 7. DISTRIBUTION OF LOADS

1. VERTICAL LOADS. For distribution of concentrated loads, use AASHO Standards, Section 3. Also see *Engineering Monograph No. 27,* Bureau of Reclamation (Bibliography).

2. HORIZONTAL LOADS.

a. Distribution of Horizontal Shears. Reinforced concrete slabs and other similar permanent structural elements may be assumed to act as horizontal diaphragms to transfer lateral loads to the resisting vertical elements. Distribution to the vertical elements shall be proportional to their rigidities, or distribution of rigidities, or both.

b. Symmetry of Elements. The center of rigidity of resisting vertical elements should coincide with the resultant of the lateral loads. Otherwise, provide for any resulting torsional moment or shear.

c. Overturning. The stability moment, computed for dead loads only, shall be a minimum of 1.5 times the overturning moment, unless the structure is anchored so as to resist the excess overturning moment. The weight of earth superimposed over footings may be included in computing the moment of stability due to dead loads.

d. Sliding. For factor of safety against sliding, refer to *Soil Mechanics, Foundations, and Earth Structures,* NAVFAC DM-7.

Section 8. COMBINED LOADS

1. HIGHWAY REQUIREMENTS. Standards for combined loads applicable to highway requirements are contained in the AASHO Standards.

2. RAILWAY REQUIREMENTS. Combined loads applicable to railway requirements are found in the AREA Manual. (See Criteria Sources.)

3. TOWERS. See Chapter 9.

4. OTHER STRUCTURES. Except as provided in specific design manuals, structures other than those indicated above shall be designed for the following combinations of loads with corresponding allowable stresses:

Load combinations	*Percentage of basic stress*
Dead + live + impact	100
Dead + wind	133
Dead + live + wind	133
Dead + live + impact + wind	133
Dead + live + impact + lateral + longitudinal forces	100
Dead + live + impact + earthquake	133
Dead + live + impact + temperature + friction + shrinkage	125
Other improbable and/or infrequent loading combinations or loads of short duration	133

Members may be proportioned for stresses greater than the basic unit stress, provided the sections thus established are not less than those required for load combinations with no increase in basic stress.

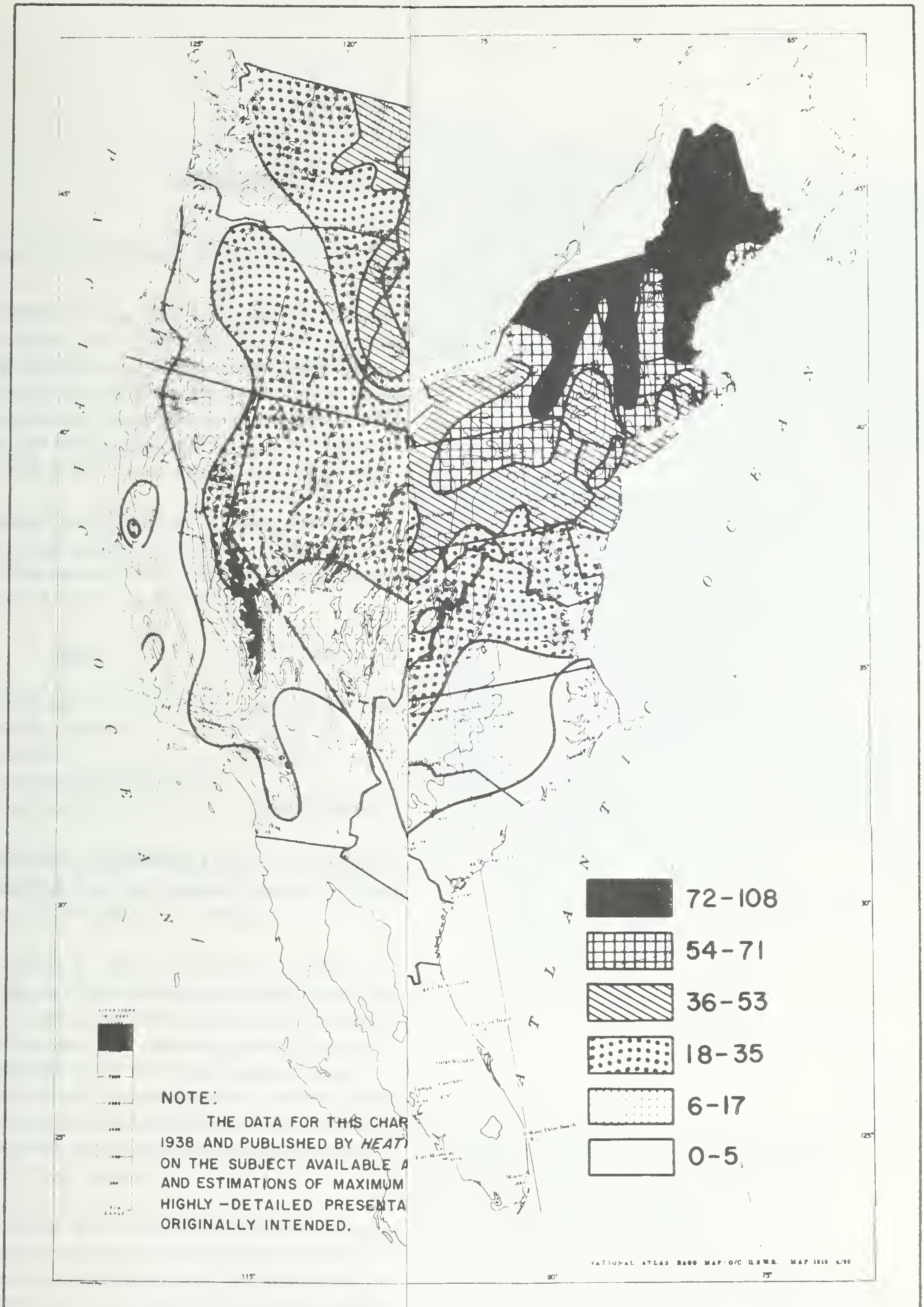


FIGURE 1
Maximum Depth (in Inches) of Frost P

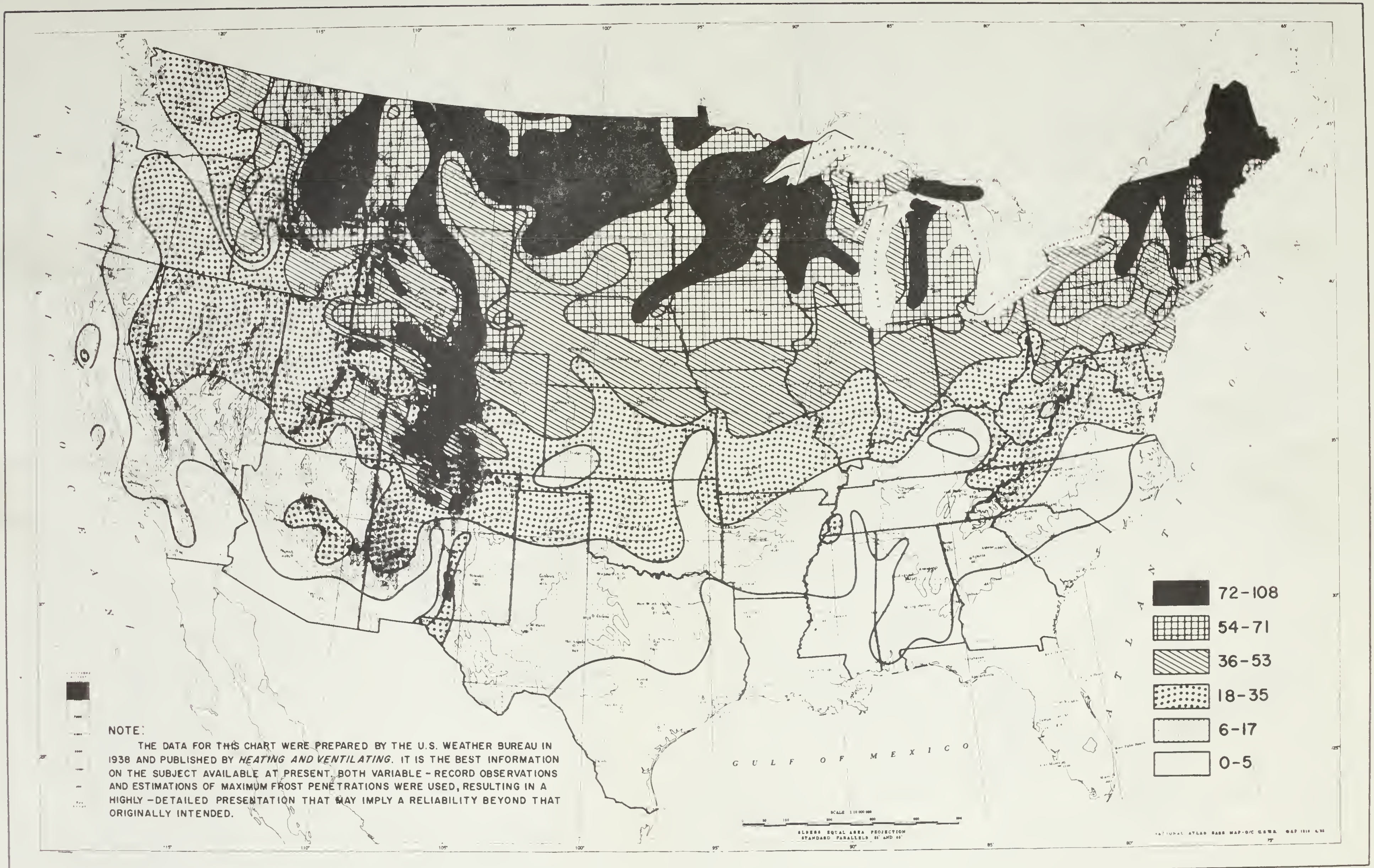


FIGURE 1-14
Maximum Depth (in Inches) of Frost Penetration for Contiguous States

CHAPTER 2. STEEL STRUCTURES

Section 1. SCOPE AND RELATED CRITERIA

1. **SCOPE.** Design criteria, as presented herein, are necessary for all types of steel structures (including temporary and prefabricated structures) except those modified for particular structures in other design manuals. Requirements for materials, fabrication, and erection are contained in NAVFAC Specification 22Y (latest revision).

2. **RELATED CRITERIA.** Certain criteria related to steel structures appear in other chapters of this design manual and in other manuals in the design manual series, as cited:

Subject	*Source*
Fire protection	NAVDOCKS DM-8
Freestanding towers	Chapter 9
Guyed towers	Chapter 9
Ultimate and working strength of wire rope	NAVFAC DM-26

3. **SERVICE CLASSIFICATION.** Steel structures are classified into three general categories – class A, class B, and class C, as follows.

a. **Class A.** Class A structures are those to which standard specifications for bridge type structures are applicable, with modifications. Included are bridges, trestles, viaducts (railway, highway, and pedestrian), and their components (beams, girders, columns, tension members, trusses, floors, bearings), certain weight-handling equipment, and piers carrying moving loads, as delineated in the specific design manuals.

b. **Class B.** Class B structures are those to which standard specifications for building-type structures are applicable, with modifications. Included in class B are all steel structures except those designated as class A (bridge type) or class C (special structures).

c. **Class C.** Class C covers special structures not readily classified in either of the above two categories, including storage tanks, cable guyed and supported structures, floating structures, and others designated as special structures in the specific design manuals.

4. **SELECTION OF MATERIAL.** Select the applicable kind of steel after considering the physical properties and characteristics given in AISC, AISI, ASTM publications.

5. **STANDARD SPECIFICATIONS.** Throughout this chapter where design criteria are obtained from cited sources, those citations are termed "standard specifications."

Section 2. ALLOWABLE STRESSES

1. **STRUCTURAL STEEL.** Standard specifications with modifications for types of structural steels and different classes of structures are contained in AISC, AISI, ASTM publications.

2. **CAST STEEL, CAST IRON, AND MALLEABLE IRON.** For allowable stresses of cast steel (ASTM-A27), cast iron (ASTM-A48), and malleable iron (ASTM-A47), use applicable portions of AASHO Standards (see Criteria Sources) for all classes of structures.

3. **WROUGHT IRON.** For allowable stresses of wrought iron (bars, ASTM-A207; plates, ASTM-A42; pipes, ASTM-A72), use applicable portions of AASHO Specifications for all classes of structures.

4. **LIGHT GAGE STEEL.** The allowable stresses in the *Specification for the Design of Light Gage Cold-Formed Steel Structural Members*, AISI (see Criteria Sources) shall be used for class B structures. Light gage steel should be used only for building-type structures.

5. **WIRE ROPE.** For ultimate and working strengths of various types of wire rope, use the criteria in *Harbor and Coastal Facilities,* NAVFAC DM-26.

6. **MODIFICATIONS.**

a. **Class C Structures.** For structures not otherwise covered, special specifications or other information available in technical literature and manufacturers' publications shall be considered in establishing allowable stresses and standards for design. Where such information is not available, it shall be left to the designer's discretion to ascertain into which category (class A or B) the structure belongs.

b. **Load Combinations.** For different load combinations, modify allowable stresses by a factor reflecting probability of occurrence as specified in Chapter 1.

c. **Corrosion and Wear.** For structural elements subject to severe exposure or wear conditions, provide special materials, special protection, and/or increased thickness of materials, rather than decreasing allowable stresses. See Section 5 for criteria.

Section 3. STANDARDS FOR DESIGN (ELASTIC THEORY)

Part 1. CLASS A STRUCTURES

1. **STANDARD SPECIFICATIONS FOR HIGHWAY BRIDGES.** See AASHO Standards.

2. **STANDARD SPECIFICATIONS FOR RAILROAD BRIDGES.** See the AREA Manual (see Criteria Sources).

Part 2. CLASS B STRUCTURES

1. **STANDARD SPECIFICATIONS.** Standard specifications for class B structures are contained in American Institute of Steel Construction (AISC) Specifications (see Criteria Sources).

2. **BUILDINGS.**

a. **Roof Modifications – Trusses, Rafters, and Purlins.**

(1) The distance between sag rods shall be taken as unsupported length when used with corrugated roofing, precast gypsum tiles, and similar construction.

(2) Consider wood sheathing and roof slabs of cast-in-place concrete and gypsum as giving continuous lateral support to purlins, provided connections thereto are adequate.

(3) The depth of purlins shall be a minimum of 1/36 of the span; however, purlins supporting plaster ceilings shall have a minimum depth of 1/24 of the span.

(4) When connections of purlins to roof trusses conform to those specified, consider the top chord of a truss as laterally supported between purlins, provided that the roof system as a whole is adequately braced. See Chapter 9.

(5) Top lines of purlins on opposite sides of roof ridge lines not having monitors shall be tied together to form a substantial ridge strut.

(6) Where the pitch of a roof is greater than 2 inches per foot, provide sag rods between purlins, including ridge purlins.

(7) Consider lateral bending moments of purlins on sloping roofs to be resisted by top flanges only.

b. **Wall Modifications – Girts.**

(1) If the preponderant part of a vertical load is applied to one flange of a girt, consider the resulting bending moment to be resisted by that flange only.

(2) The distances between sag rods shall be taken as the span length for vertical bending, and as the unsupported length for horizontal bending, except that when wood sheathing is used, consider the outer flanges as supported throughout, provided connections thereto are adequate.

(3) The depth of girts shall be not less than 1/36 of the span.

c. **Columns and Beams.**

(1) Columns. For one-story buildings with only two columns (of the same section) per bent, and designed as a bent, allocate wind loadings as follows.

(a) Divide equally between the two columns wind loadings on the wall, above the bottom of a roof truss or above the point of connection of an effective knee-brace, together with the horizontal component of the wind on the roof.

(b) Distribute wind loadings on the wall between these points (see (a), above) and the base, three-fourths of the windward column, and one-fourth to the leeward column.

(2) *Elevator Beams and Supports.* Allowable deflections under static loads shall not exceed:

(a) For overhead machine beams of all alternating-current installations, and for direct-current installations where car speeds exceed 150 feet per minute (fpm) – 1/2000 of the span.

(b) For overhead machine beams of direct current installations where car speeds are 150 fpm or less – 1/1666 of the span.

(c) For overhead beams supporting machine beams – 1/1666 of the span.

(d) For overhead sheave beams – 1/3333 of the span.

d. Effect of Heat on Structural Steel. In lieu of the part in the AISC Specifications concerned with the effect of heat on structural steel, use the criteria in Section 5.

3. CRANE RUNWAYS AND SUPPORTS.

a. Lateral Loads. Consider bending from lateral loads to be resisted only by loaded flanges or chords.

b. Longitudinal Loads. For stress computations, assume loads carried by the area of top flange. For computations of L/r, consider entire runway girder.

c. Wheel Stops. Providing removable stops or bumpers at ends of the runway shall include:

(1) Proportioning stops for maximum reactions on runway and crane traveling at rated speeds.

(2) Computing stresses from energy equation using coefficient of restitution of 0.5.

4. FREESTANDING TOWERS. See Chapter 9 for criteria.

5. SELF-SUPPORTING STACKS.

a. Design Details. Design details shall include the following points:

(1) The ratio of diameter to shell thickness shall be a maximum of 480.

(2) The deflection at the top of a stack shall be a maximum of 1/100 of the stack height.

(3) Additional compressive stresses in a stack plate due to the weight of the stack plate or light lining (maximum of twice the weight of the stack plate) may be neglected.

b. Typical Details. Typical details applicable to self-supporting stacks are contained in Figure 2-1.

Part 3. CLASS C STRUCTURES

1. LIGHT GAGE COLD-FORM STEEL STRUCTURES. Current AISI Specifications shall govern design of structural members, and connections in buildings utilizing light gage steel. Also see *Light Gage Cold-Formed Steel Design Manual,* AISI (Bibliography).

2. STORAGE TANKS.

a. Elevated Tanks. The design of elevated tanks for water storage shall conform to the *Standard for Steel Tanks, Standpipes, Reservoirs, and Elevated Tanks for Water Storage,* AWWA (see Criteria Sources), modified as follows:

(1) Where elevated storage tanks are used for storage of fluids other than water, the tank design shall conform to the requirements stated in Chapters 3 and 9 and in *Liquid Fueling and Dispensing Facilities,* NAVFAC DM-22, as applicable to such fluids.

(2) The design of the tank supports (tower) shall conform to the AWWA Standard, as modified.

(3) Modifications to the AWWA Standard follow:

(a) Section 1 – General: The provisions of this section shall not apply.

(b) Section 3.2: Substitute loading provisions indicated in Chapter 1 of this design manual, except that the provisions of paragraphs 3.2.2 and 3.2.6 of the AWWA Standard should apply.

(c) Paragraph 3.4.3: Substitute increased allowable stress values for combined loads indicated in Chapter 1.

(d) Paragraph 3.10: See Chapter 1 for data on corrosion losses. Corrosion allowances shall be added to the flanges of beams and channels as well as to the webs.

(4) Where horizontal girders are used as balcony floors, minimum girder widths shall be as follows:

Tank capacity (gallons)	*Minimum girder widths (inches)*
75,000 or less	24
Over 75,000 to 100,000	27
Over 100,000 to 200,000	30
Over 200,000	36

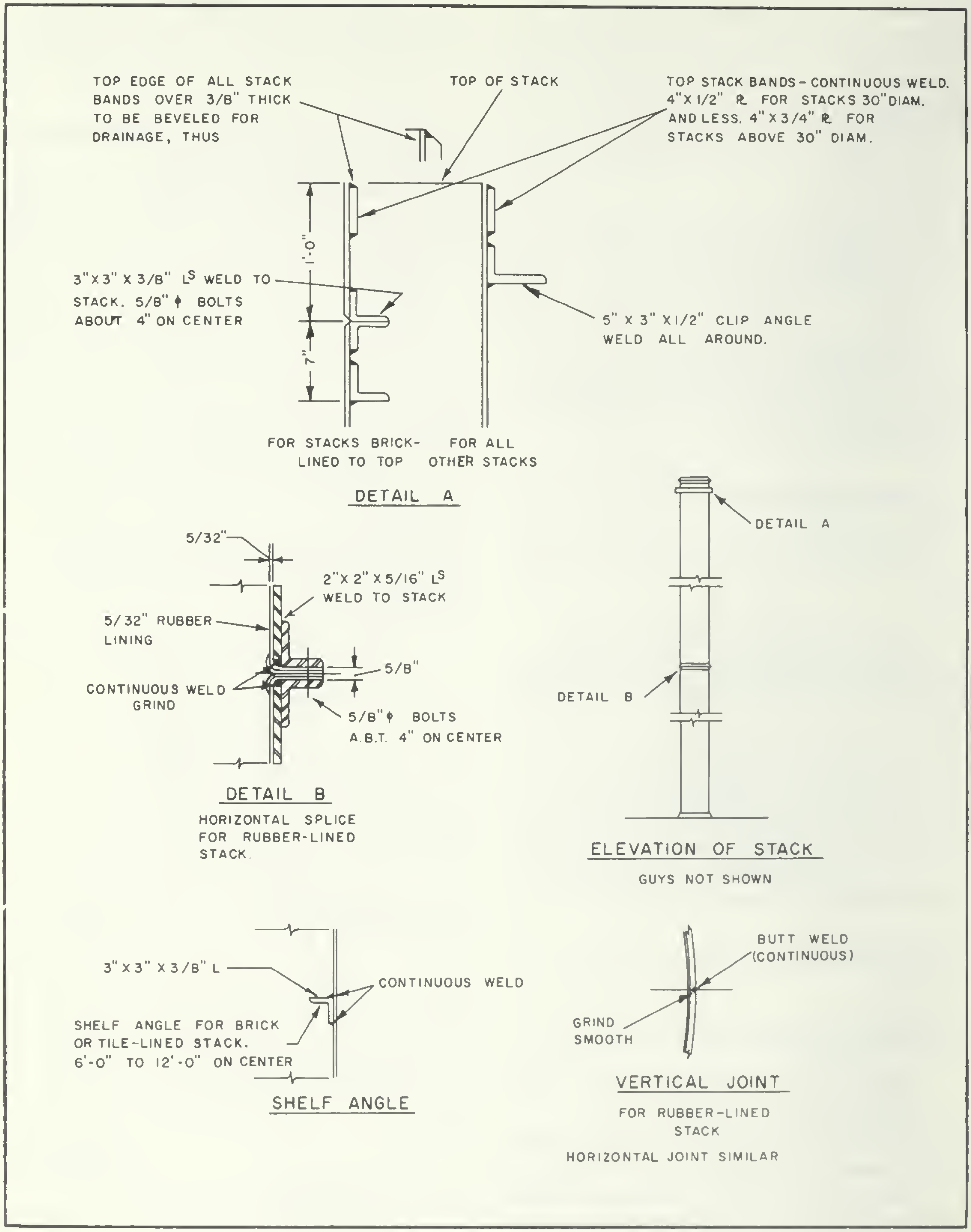


FIGURE 2-1
Steel Stack Details

(5) Tank roofs shall be conical; those with diameters in excess of 24 feet shall be supported on appropriate structural steel framing.

(6) Thickness of hemispherical bottoms shall be proportioned in accordance with Paragraph 5.11 of the AWWA Standard, but not less than the thickness of the lowest shell plate in the cylindrical part.

(7) For riser pipes, the ratio of diameter to shell thickness shall be a maximum of 480.

b. Surface Tanks. Standards to be observed in surface tank design include:

(1) Design of surface mounted tanks for water storage shall conform to the requirements of the AWWA Standard relating to "Standpipes and Reservoirs," modified as indicated previously for elevated tanks.

(2) Design of surface mounted tanks for storage of liquid fuel shall conform to requirements of American Petroleum Institute (API) Standard 650, (see Criteria Sources) modified as follows:

(a) Paragraph 3.3.2, Standard 650 Delete the second sentence and substitute: "The tension in each ring shall be computed assuming the pressure of the lower edge of the ring acts undiminished on the entire area of the ring."

(b) Paragraph 3.5.2, Standard 650 Substitute loading provisions of Chapter 1 of this design manual. Minimum live loading shall be 25 psf.

(c) Provisions of Chapter 1 of this design manual relating to increased allowable stresses under combined loadings shall apply.

(d) Allowance shall be made in thickness of metal for corrosion loss.

(e) A temperature differential of 40°F shall be assumed between inside and outside faces of tanks.

c. Subsurface Tanks. Design of subsurface tanks shall conform to preceding requirements for surface tanks, with the following additional provisions:

(1) Roof Loads. Roof loads shall allow for weight of earth cover.

(a) Where passage of vehicles over tank locations is possible, wheel loads shall be approximately in accordance with provision of the AASHO Standards for distribution of wheel loads through fill.

(b) Where vehicle loads are known, select appropriate loading classification in AASHO Standards, but not less than H10.

(c) Where vehicles cannot pass over roofs, surcharge loads due to personnel may be neglected.

(2) Internal Pressure. Tanks for storage of gasoline, jet engine fuels, and similar volatile liquids shall be designed for an internal pressure of 3 pounds per square inch (psi) and vacuum of 0.5 psi.

(3) Ground Water Effects. In the tank design, consider hydrostatic pressures and uplift due to presence of ground water. Ground water levels should be determined by use of observation wells with allowance for seasonal changes in level. The minimum factor of safety against uplift shall be 1.5, considering the tank empty.

(4) Lateral Earth Pressure. Determine lateral earth pressures in accordance with *Soil Mechanics, Foundations, and Earth Structures,* NAVFAC DM-7. Passive earth pressure shall not be considered to resist internal tank pressures, unless the allowable movements of tank walls are sufficient to develop such passive pressures. Movements of one to several inches normally are required to develop passive earth pressures.

(a) Active earth pressure (or ground water pressure) shall not be deducted from internal pressure when computing stresses in a tank shell.

(b) Designs shall allow for active lateral earth pressures, maximum ground water pressure, and full tank suction acting with the tank empty.

(c) Shell strengths for cylindrical tanks shall be checked for buckling under the action of lateral, external pressures using formulas for buckling of elastic rings (see standard texts on the theory of elasticity). Such checks shall be made for lateral pressures acting on the entire circumference of a tank and on half the circumference with the other half unloaded. For steel tanks, use a safety factor of four against buckling.

(5) For 10 PSI over pressure design, see *Index of Design Standards and Criteria,* NAVFAC P127.

3. CABLE-GUYED TOWERS.

a. Standard Specifications. Standard specifications for cable-guyed towers are contained in AISC Specifications. For additional information, see Chapter 9.

b. Guys. Guys shall be either prestressed bridge ropes or strands. The relatively high modulus of elasticity of these types reduces the amount of stretch.

c. Modifications. To facilitate procurement of standard, commercially manufactured steel radio towers, guyed-pole types of 300 feet or less in height, substitution of the latest *Standard RS-222,* Electronic Industries Association is permitted.

4. CABLE-GUYED STACKS. Guyed stacks shall be designed in accordance with requirements previously established for self-supporting stacks, except as follows:

(1) Guys shall be either prestressed bridge ropes or strands.

(2) For locations of guys, arrangement, and design assumptions, see criteria for guyed towers in Chapter 9.

(3) Typical details shall be the same as for self-supporting stacks.

Part 4. LIMITED LIFE STRUCTURES

1. MODIFICATIONS OF STANDARD SPECIFICATIONS. The design of a steel structure, where usage is limited to less than 1 year, may be based on an increase of 33 percent in allowable stresses, but the total increase (including increases for load combinations) shall not exceed 40 percent. Where life expectancy is 1 year or more, consult NAVFAC HQ for guidance regarding increase in allowable stresses. Other modifications in design standards and details may be made at the discretion of the designer.

Part 5. PREFABRICATED STRUCTURES

1. STANDARDIZED DESIGNS. Prefabricated structures represent standardized designs adaptable to mass production. Because of the number of framing members used for mass production, the members are analyzed and proportioned with care in order to reduce deadweight and increase efficient use of materials. Manufacturers' catalogs should be consulted for commercially available types. See *Architecture,* NAVDOCKS DM-1, for additional design considerations.

Section 4. STANDARDS FOR DESIGN OF CLASS B STRUCTURES (PLASTIC THEORY)

1. APPLICATION. Some steel structures that are subject to certain load conditions can be designed safely and economically on the basis of the so-called plastic theory. This design concept may be used alternatively to the conventional elastic theory, if deemed advisable by the engineer.

2. PLASTIC THEORY AND DESIGN. To obtain a uniform margin of safety for indeterminate structures of structural steel, a rational analysis is made to obtain the ultimate load. This capacity load is a designated load factor times the design load. Advantage is taken of the characteristic ductility of structural steel when stressed beyond the yield point. The development, assumptions, theory design, applications, and tests of this method are covered in numerous papers in the technical literature as well as several complete texts on the subject.

3. STANDARD SPECIFICATIONS. Standard specifications for the designs of structural elements such as beams and columns are contained in the *Manual of Steel Construction,* AISC (see Criteria Sources), and shall be used unless otherwise noted. Details and bracing requirements also are covered in this specification.

4. TYPICAL DESIGNS. Typical design problems and illustrative examples are available in a number of textbooks and other publications (see Bibliography). To facilitate application to some representative problems, refer to *Plastic Design in Structural Steel,* AISC (see Criteria Sources), for design aids in the form of charts and tables.

Section 5. SPECIAL CONSIDERATIONS

Part 1. EXPANSION JOINTS

1. CLASS A STRUCTURES. Applicable portions of the AASHO Standards and AREA Specifications shall govern provisions for expansion and contraction.

2. CLASS B STRUCTURES. Where required, joints should be provided along the framing and siding at the transverse lines selected, preferably all in one vertical plane, as follows:

(1) Where structures are more than 300 feet in length.

(2) At junctures of T-, L-, U-shaped and other irregularly shaped buildings.

(3) Where there is such a change in the type of foundation construction as to expect differential settlements.

Part 2. CORROSION

1. TYPES OF CORROSION.

a. Atmospheric Corrosion. Relative corrosive effects of atmospheres at different locations throughout the world are contained in *Corrosion Prevention and Control,* NAVDOCKS MO-306, Table 4.

b. Sea Water Corrosion. For continuously submerged conditions, the rate of loss of structural carbon, copper alloy, wrought iron and high-strength, low-alloy steels is approximately 0.004 inch per year for each surface exposed.

c. Corrosion in Inland Waters. Tests in uncontaminated water with high oxygen content indicate no difference in corrosion rates for carbon, copper alloy, or high-strength steels. Tests indicate that greater corrosion occurs for all steels with increasing contamination; however, high-strength steels showed less corrosion with increase in contamination when compared with other steels.

d. Corrosion in Soils. Tests made by the National Bureau of Standards (NBS) indicate that the type of soil influences the degree of corrosion much more than the differences in composition between carbon steel and high-strength, low-alloy steel.

e. Electrolytic Corrosion. Do not use dissimilar materials without proper insulators or cathodic protection or both.

2. TIME-CORROSION CURVES.

See Figure 2-2 for typical time-corrosion curves for industrial and marine atmospheres and various types of steels. See Figure 2-3 for corrosion in soils.

3. DESIGN MEASURES AGAINST CORROSION.

To forestall the effects of corrosion in steel structures, the following methods should be considered, where applicable.

a. Details. Design box-shaped members so that all inside surfaces may be readily inspected, cleaned, and painted; or close them entirely.

(1) In outdoor structures, the flanges of two angle members, if not in contact, shall have a minimum of 5/8 inch of space between them.

(2) Pockets or depressions in outdoor structures shall have drain holes or be filled with concrete, mastic, or grout.

b. Increase in Metal Thickness. Allow for corrosion by increasing the metal thickness beyond the stress requirements. The extent of this increase will depend on service conditions and life, and may be estimated from Figures 2-2 and 2-3.

c. Use of Corrosion-Resistant Steels. Refer to Figure 2-2 for comparison of corrosion resistance of different types of steels.

d. Corrosion Prevention. Steel sheet piling should be capped with concrete to eliminate rapid corrosion of the exposed ends; for waterfront structures, steel sheet piling should be encased in concrete to 2 feet below mean lower low water level. Consideration should be given to providing bonded cables for future connection for cathodic protection of the piling exposed under water, if cathodic protection is not installed initially. Consideration also should be given to provision for cathodic protection of tie rods for steel sheet pile construction, in addition to protective coatings.

e. Corrosion in Tropical Climates. See Part 4.

Part 3. WEAR

1. DESIGN PROVISIONS.

a. Increase in Metal Thickness. Allow for wear by increasing the metal thickness of those portions of the design section subject to wear, beyond the stress requirements. The amount of such increase depends on the material to be handled and on the desired service life. Definite data on wear are not available. Therefore, a designer

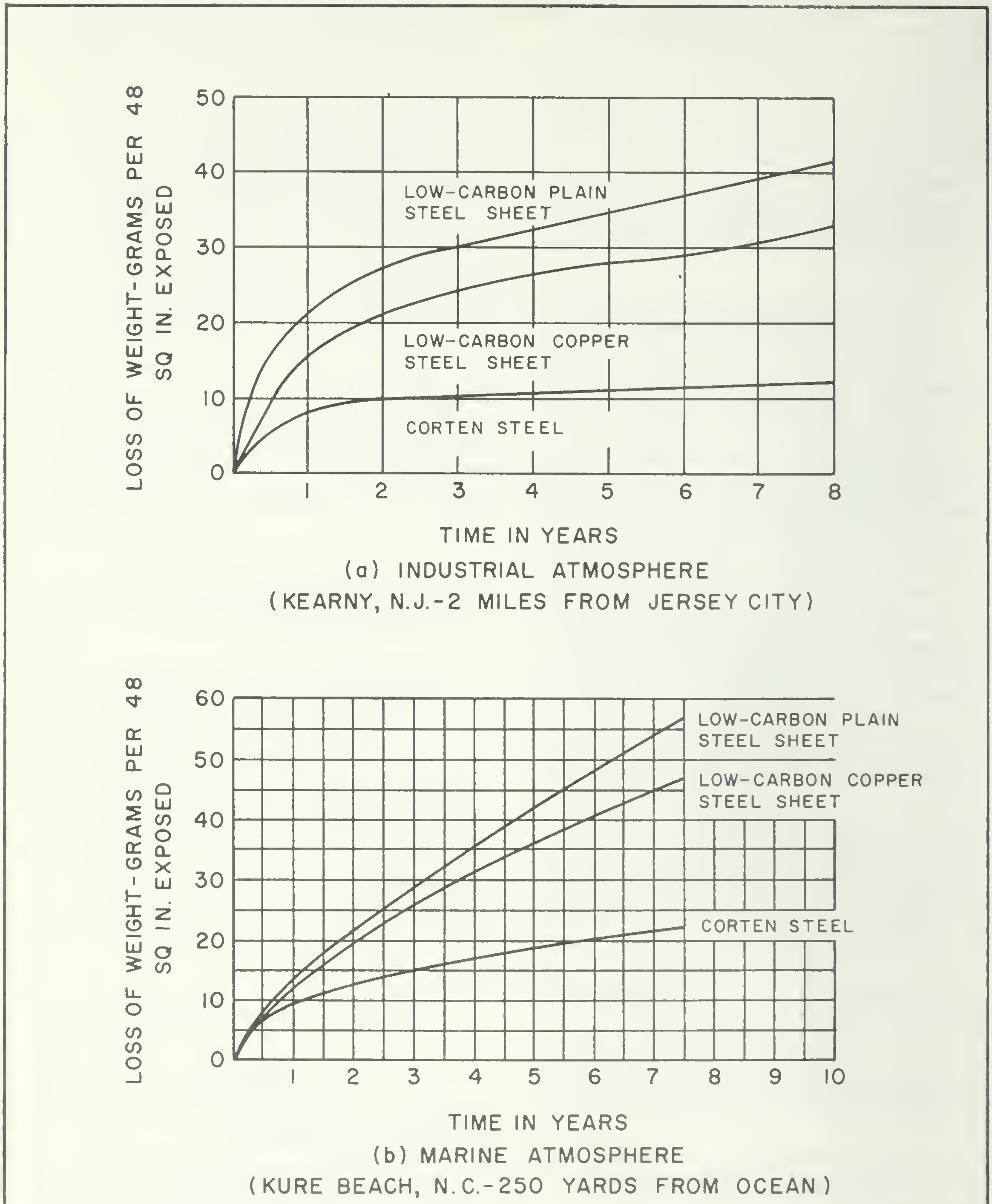


FIGURE 2-2
Time-Corrosion Curves for Industrial and Marine Atmospheres

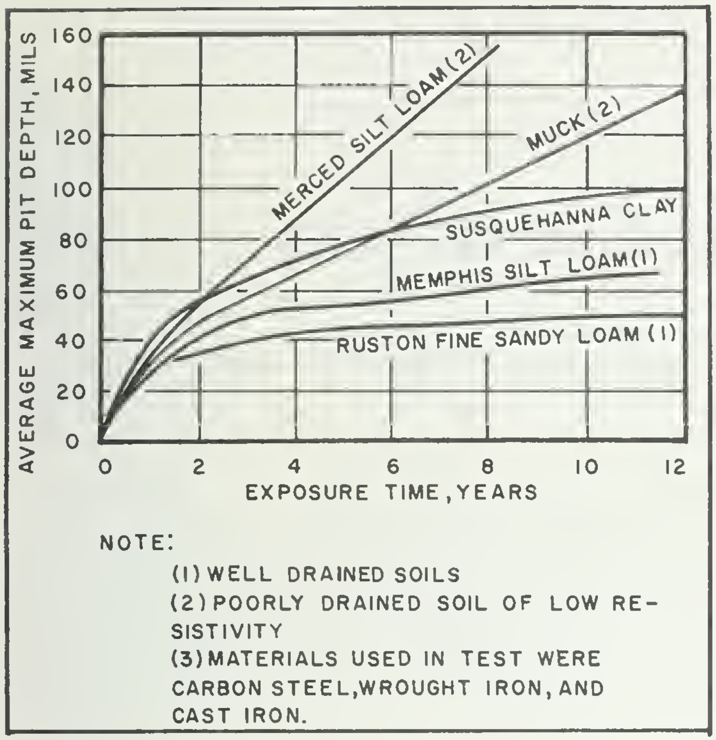


FIGURE 2-3
Time-Corrosion Curves in Soils

should estimate wear requirements on the basis of previous experiences or similar conditions (or both) at existing installations.

b. Liner Plates. Consider the use of replaceable liner plates where extremely severe wear conditions occur.

Part 4. CLIMATIC REQUIREMENTS

1. ARCTIC AND ANTARCTIC ZONES. The properties of ferrous metals are affected by the very cold climatic conditions experienced in arctic and antarctic zones, and such factors should be considered in design. Design criteria for arctic and antarctic zones are contained in *Cold Regions Engineering,* NAVFAC DM-9.

2. TROPIC ZONES. Increased temperatures, as in tropic zones, do not affect the load capacity of steel members. However, severe corrosion may take place in marine atmospheres in these areas.

a. Materials. Consider the use of ASTM Specification A242 steel for locations subject to severe atmospheric corrosion. This specification should include: "The steel shall have a corrosion resistance rating at least twice that of ordinary carbon steel after 5 years exposure in severe marine atmosphere; the corrosion rating shall be based on time-corrosion curves showing corrosion loss of comparative panels after at least 5 years exposure."

b. Fastenings. Fastenings of dissimilar metals should not be used. However, should it be necessary to use dissimilar metals, they must be isolated from contact with each other.

(1) Fasteners, rather than welds, should be used for securing roofing sheets to base structures.

(2) Structural bonding of metal, wood, glass, and synthetic resins to each other or in combination should be by means of epoxy resin adhesive, Military Specification (MIL-A-8623).

c. Embedded Steel. Structural members, exterior railings, handrails, fences, guardrails, and anchor bolts embedded in concrete shall be zinc-coated.

Part 5. FIRE PROTECTION

1. REQUIREMENTS. Minimum requirements for various classes of construction are given in *Fire Protection Engineering,* NAVDOCKS DM-8.

Part 6. ELEVATED TEMPERATURES

1. PROPERTIES. For properties of two steels at elevated temperatures, see Table 2-1. Modify applicable allowable stresses by proportionate reductions in yield strengths.

TABLE 2-1
Properties of Steel at Elevated Temperatures

Type of steel	Temperature degree F	Yield strength 0.2% offset psi	Tensile strength psi	Percent elong. in 2 in.
ASTM	80	36,000	72,000	29.8
A36	400	34,600	80,100	18.0
1 in.	800	31,700	60,500	29.8
thick.	1,000	26,200	38,900	31.5
	1,200	13,000	16,200	38.3
USS Cor-	80	60,200	87,200	28.8
ten 1 in.	400	51,500	82,200	24.2
thick.	800	46,800	72,400	31.2
(A242)	1,000	36,700	51,400	22.5
	1,200	21,900	28,600	28.2

CHAPTER 3. CONCRETE STRUCTURES

Section 1. SCOPE AND RELATED CRITERIA

1. **SCOPE.** This chapter contains design criteria for all concrete construction, except floating structures and pavements. Construction requirements and specifications are contained in NAVFAC Specification 13Y (latest revision), and shall govern when in conflict with the current ACI Building Code. (See Criteria Sources.)

2. **RELATED CRITERIA.** Certain criteria related to concrete structures appear in other chapters of this manual and in other manuals in the design manual series, as follows.

Subject	*Source*
Fire protection	NAVDOCKS DM-8
Service classification	Chapter 2
Steel tank design	Chapter 2

3. **CLASSES OF CONCRETE.** Select the concrete strengths to be used after considering the application guide in Table 3-1.

4. **SERVICE CLASSIFICATIONS.** Like steel structures, concrete structures shall be grouped into classes A, B, or C. (See Chapter 2.)

5. **STANDARD SPECIFICATIONS.** Throughout this chapter, where design criteria are to be obtained from cited sources, those citations are termed "Standard Specifications."

6. **ULTIMATE STRENGTH DESIGN OF CONCRETE STRUCTURES (BASED ON ELASTIC ANALYSIS).** See *Building Code Requirements for Reinforced Concrete* (ACI-318). (See Criteria Sources.)

Section 2. STANDARDS FOR DESIGN OF CONCRETE STRUCTURAL ELEMENTS

Part 1. CLASS A STRUCTURES

1. **BRIDGES.**

a. Highway Bridges. Standard specifications for highway bridges are contained in *Standard Specifications for Highway Bridges,* AASHO. (See Criteria Sources.)

b. Railroad Bridges. Standard specifications for railroad bridges are contained in *Specifications for Design of Plain and Reinforced Concrete Members,* AREA. (See Criteria Sources.)

2. **CLASS A STRUCTURES OTHER THAN BRIDGES.** Specifications for class A structures other than bridges are contained in *Building Code Requirements for Reinforced Concrete* (ACI-318) (see Criteria Sources) with modifications as indicated in Table 3-2.

Part 2. CLASS B STRUCTURES

1. **STANDARD SPECIFICATIONS.** Standard specifications for the design of slabs, beams, girders, columns, walls, and footings are found in *Building Code Requirements for Reinforced Concrete* (ACI-318). (See Criteria Sources.)

2. **BUILDING CODE MODIFICATIONS.** Revise sections of the Standard Specification (see Paragraph 1) according to Table 3-2.

Part 3. CLASS C STRUCTURES

1. **TANKS.** The design shall conform to the applicable provisions for steel tanks (see Chapter 2),

TABLE 3-1

Classes of Concrete

Class	General application
B (1500 lb).	1. Unreinforced mass concrete, not exposed to atmospheric conditions or other deteriorating agents. 2. Where mass rather than strength is principal condition. 3. Low strength such as filling purposes.
C (2000 lb).	1. Plain foundation walls. 2. Mass footings with small percentage of reinforcing. 3. Light curtain walls not to be exposed to sea water, frost action, or similar destructive agents.
D (2500 lb).	1. Reinforced concrete buildings (except as specified elsewhere in this chapter) and similar work not to be exposed to sea water or similar destructive agents. 2. Filling for hollow structures in sea water except where deposited under water. 3. Cast-in-place concrete piles for shore use. 4. Heavily reinforced footings. 5. Retaining walls subject to ordinary exposure conditions. 6. Concrete exposed to frost action where 2000-lb concrete would otherwise be used.
E (3000 lb).	1. Reinforced members in buildings and similar structures where smaller sections are necessary for clearances or where higher working stresses are economical, such as columns and long heavy girders. 2. Precast concrete piles for shore use. 3. Structures to be impervious to noncorrosive liquids such as tanks and reservoirs for fresh water and the heavier mineral oils. 4. Walls subjected to severe exposure conditions. 5. Conduits for noncorrosive liquids. 6. Waterfront structures on fresh water. 7. Mass concrete exposed to sea water or other deteriorating agents except as noted in this chapter. 8. Reinforced concrete structures over sea water which are sufficiently elevated so that they are not ordinarily wetted by salt water.
F (3500 lb).	1. Columns in multistory buildings carrying heavy loads. 2. Reinforced concrete including precast concrete piles in contact with sea water, alkaline soils or waters, or other destructive agents. 3. Reinforced concrete decks of waterfront structures where the underside is frequently wetted by salt water. 4. Concrete structures requiring high degree of impermeability, such as tanks for the lighter mineral oils and for animal and vegetable oils. 5. Concrete deposited under water. 6. Mass concrete exposed to sea water from 3 ft below low water to 3 ft above high water or above normal wave action. 7. Reinforced concrete chimneys. 8. Precast concrete framing.
G (4000 lb).	1. Prestressed and precast concrete structures. 2. Usually important structures under extreme conditions of exposure.
H (5000 lb).	1. Prestressed and precast concrete construction and special structures.

except that the minimum safety factor for ring buckling shall be 2. For additional information, see *Circular Tanks Without Prestressing*, No. ST57, and *Rectangular Concrete Tanks*, No. ST63, PCA. (See Criteria Sources.)

2. **CHIMNEYS.** Use *Standard Specification for the Design and Construction of Reinforced Concrete Chimneys* (ACI-505). (See Criteria Sources.)

Part 4. PRESTRESSED STRUCTURES

1. **STANDARD SPECIFICATIONS.** For design criteria, see *Building Code Requirements for Reinforced Concrete* (ACI-318) and *Tentative Recommendations for Prestressed Concrete* (ACI-ASCE Joint Committee-323), and *Standard Specifications for Highway Bridges*, AASHO. (See Criteria Sources.)

2. **LIVE LOADS.** For prestressed structures, particular attention shall be given to deflections and effects of partial live loadings.

3. **WORKING STRESSES IN TENDONS.** Use Table 3-3 to estimate working stresses in tendons.

Part 5. PRECAST STRUCTURES

1. **FLOOR AND ROOF UNITS.** For design criteria, see *Building Code Requirements for Reinforced*

TABLE 3-2

Modifications to the Building Code Requirements for Reinforced Concrete (ACI-318)

Subject	Modification: Service Classification A (Other than bridges)	Modification: Service Classification B
Concrete protection for reinforcement.	Add the following: Where the concrete is exposed to the action of sea water, salt spray, alkali, or other active destructive agents, the minimum concrete cover over main reinforcing bars shall be 2 inches for slabs and 2½ inches for beams and girders. For piles and similar members extending below the water line the minimum cover over main bars shall be 3 inches from a point 10 feet below mean low water to a point 10 feet above mean high water; elsewhere in these members the minimum cover shall be 2½ inches. For prestressed concrete piles, the minimum clear cover shall be 2 inches over the ties. For the underside of decks of piers, etc., which are sufficiently elevated so that they are not wetted by salt water, and for all top surfaces, the minimum cover may be reduced to 1½ inches for slabs and 2 inches for beams and girders. Tanks and reservoirs designed to contain fresh water and other nondeteriorating substances shall have a clear cover over the reinforcement of not less than 1½ inches for slabs and 2 inches for beams and girders.	
Design general considerations.	Add the following: Coefficient of expansion of unreinforced concrete shall be taken as 0.0000055 per degree F. and .000006 per degree F. for reinforced concrete. Maximum shrinkage of concrete due to drying shall be taken as 0.0005 of its length.	Same as for Service Classification A (Other than bridges).
Flat Slabs Design by empirical methods	Add the following: Marginal beams at all discontinuous edges of flat slabs shall be designed to resist a torsional moment at each end equal to one-half the negative moment in the middle strip at the discontinuous edge. The torsional moment will induce shearing stresses in the beam which are computed from the following formula. $$v_t \approx \frac{9\ M_r}{2hb^2}$$ where v_t = maximum torsional unit shearing stress, psi (this occurs at midheight, on the outside and inside faces of the beam) M_r = torsional moment in inch-pounds (one half of the negative moment at the beam line at the middle strip) b = width of spandrel beam in inches h = height of spandrel beam in inches The torsional unit shearing stress, v_t, is a measure of the diagonal tension resulting from the torsional moment and shall be combined with the shearing	Same as for Service Classification A (Other than bridges).

TABLE 3-2 (Continued)
Modifications to the Building Code Requirements for Reinforced Concrete (ACI-318)

Subject	Modification	
	Service Classification A (Other than bridges)	Service Classification B
	stress v due to the direct load. The sum of the two shearing stresses shall not exceed the allowable value for direct shear plus torsional shear.	
Footings.	Add the following: Plain concrete footings used on rock do not act in accordance with conventional assumptions for footings founded on yielding materials. The top area must be large enough to provide for a proper distribution of the load from the wall or column. The area of the base of the footing is determined from the allowable unit pressure on the rock and the total load on the footing, including its own weight. The depth of the footing is determined from the assumption that the load is carried through the concrete at an angle of 30 degrees with the vertical; consequently, plain concrete footings can be as effective as reinforced footings.	Same as for Service Classification A (Other than bridges).

Concrete (ACI-318) and *ACI Minimum Standard Requirements for Precast Concrete Floor and Roof Units* (ACI-711). (See Criteria Sources.)

2. **THIN SECTIONS.** Design criteria for precast thin sections are contained in *ACI Standard Minimum Requirements for Thin-Section Precast Concrete Construction* (ACI-525). (See Criteria Sources.)

Part 6. LIMITED LIFE STRUCTURES

1. **APPLICATION.** Where possible, avoid the use of concrete in structures with life expectancy less than 5 years unless it is demonstrated to provide greatest economy. Consider cost of removal if appropriate. When the use of concrete cannot be avoided, however, such structures shall be of conventional design.

2. **MODIFICATIONS OF STANDARD SPECIFICATIONS.** Allowable stresses for concrete and reinforcements may be increased as indicated in subparagraphs a and b based on engineering judgment. Consider the intended use of the structure.

a. **Concrete.** For concrete, increase 25 percent, but the total increase (including increases for load combinations) shall not exceed 40 percent.

b. **Reinforcement.** For reinforcement, increase 25 percent, but the increase shall not exceed 28,000 psi.

3. **MODIFICATIONS OF CONCRETE MIX.** Modify the mix for temporary structures to attain more economical concrete as described in subparagraphs a and b that follow.

a. **Water-Cement Ratio.** Increase water-cement ratio to maximum values.

b. **Aggregates.** Allow the use of substandard materials, if the strength of the resultant mix is not impaired.

4. **REDUCTION OF COVER.** Economies resulting from decreases in cover requirements are insignificant, and departures from standard requirements should be avoided.

TABLE 3-3
Properties of Prestressing Tendons

Approximate ultimate strength		
Type	Ultimate strength – psi	
Wires of varying diameters and make	200,000 - 330,000	
Strands of 7 uncoated small wires	230,000 - 270,000	
Strands of 19 or more galv. wires	200,000 - 220,000	
Strands of 19 or more uncoated wires	220,000 - 240,000	
Bars	140,000 - 170,000	
Approximate yield point and proportional limit (in terms of ultimate strength f_s')		
Type	Yield point at 0.2% set	Proportional limit
Wires as drawn	0.75	0.35
Prestretched	0.85	0.55
Time-temperature treated	0.87	0.70
Galvanized	0.85	0.55
Strands, pretensioning as drawn	0.85	0.35
Stress-relieved	0.90	0.75
Strands, post-tensioning prestretched	0.85	0.55
Bars	0.90	0.60
Approximate average values for secant modulus at proportional limit		
Type	Secant modulus, psi	
Wires	27,000,000 - 30,000,000	
Strands for pretensioning and stress-relieved	27,000,000 - 29,000,000	
Strands for post-tensioning and prestretched	24,000,000 - 26,000,000	
Bars	25,000,000 - 28,000,000	

Section 3. SPECIAL CONSIDERATIONS

1. **FROST DEPTH.** Locate footings below frostline. The location of the frostline is indicated in Figure 1-14 and Tables 1-5 and 1-6. Except where required by local conditions (for example, ground water elevations and temperate climates), use a minimum depth of 2 feet below grade.

2. **LIGHTWEIGHT AGGREGATE CONCRETE.** For design criteria see *Building Code Requirements for Reinforced Concrete* (ACI-318) (see Criteria Sources) and modifications indicated in Table 3-2.

a. Evaluation of n. Determine "n" values from rapidly conducted compression tests of standard 6- by 12-inch cylinder specimens of the proposed mix. Values of n shall be at least 1.5 times the value specified in the standard specification for natural stone concrete of the same compressive strength.

b. Property Variations.

(1) *Strength.* The strength of concrete made with expanded shale and clay is relatively high and compares favorably with that of ordinary concrete. Pumice, scoria, and some expanded slags produce a concrete of intermediate strength; perlite, vermiculite, and diatomite produce a concrete of very low strength.

(2) *Insulation Properties.* The insulation properties of the low-strength concretes, however, are better than those of the heavier, stronger concretes. The insulation value of the heaviest material (crushed shale and clay concrete) is about four times that of ordinary concrete.

(3) *Shrinkage.* All the lightweight aggregates, with the exception of expanded shales and clays and scoria, produce concrete which is subject to high shrinkage.

c. Cinder Concrete.

(1) *Weight.* Cinder concrete weighs 85 pounds per cubic foot (pcf). When natural sand is added to increase workability, the weight increases to 110 to 115 pcf.

(2) *Combustible Content.* Limit the combustible content of cinders to 35 percent maximum, by dry weight. Restrict sulfides to 0.45 percent maximum and sulfates to 1 percent maximum.

(3) *Residual Sulfur Compounds.* Steel framing supporting cinder concrete construction shall be painted to resist deterioration caused by residual sulfur compounds.

d. Expanded Slag Concrete. Expanded slag concrete weighs 75 to 110 pcf. See Table 3-4 for values of "n."

e. Expanded Shale and Clay Concrete. Expanded shale and clay concrete weighs 90 to 110 pcf. See Table 3-4 for values of "n."

TABLE 3-4
Suggested Data for Expanded Shale Clay and Slag Aggregate Concrete

$n = \dfrac{29 \times 10^6}{33\ w^{1.5}\sqrt{f'_c}}$	$f_c = 0.45\ f'_c$	$f_s = 20{,}000$ psi	$E_s = 29 \times 10^6$ psi
assume w = 145 pcf	$k = \dfrac{1}{1 + \dfrac{f_s}{n\ f_c}}$	$K = \dfrac{f_c}{2}\ kj$	$a = \dfrac{f_s j(ave)}{12{,}000}$
$n = \dfrac{504}{\sqrt{f'_c}}$	$j = 1 - \frac{1}{3}k$	for use in $M_r = Kbd^2$	for use in $A_s = \dfrac{M}{ad}$

f'_c	f_c	n	k	j	K	a(ave)
			$f_s = 20{,}000$			
2500	1125	10.1	0.362	0.879	179	1.44
3000	1350	9.2	0.383	0.872	226	1.44
3500	1575	8.5	0.401	0.866	274	1.44
3750	1688	8.2	0.408	0.864	298	1.44
4000	1800	8.0	0.419	0.860	324	1.44
4500	2025	7.5	0.432	0.856	374	1.44
5000	2250	7.1	0.444	0.852	426	1.44
			$f_s = 24{,}000$			
2500	1125	10.1	0.321	0.893	161	1.76
3000	1350	9.2	0.341	0.886	204	1.76
3500	1575	8.5	0.358	0.881	248	1.76
3750	1688	8.2	0.366	0.878	272	1.76
4000	1800	8.0	0.375	0.875	295	1.76
4500	2025	7.5	0.388	0.871	342	1.76
5000	2250	7.1	0.400	0.867	390	1.76

f. Natural Aggregates.

(1) *Pumice.* Concrete with pumice aggregate weighs 90 to 100 pcf.

(2) *Scoria.* Concrete made with scoria weighs 90 to 110 pcf.

(3) *Perlite.* Concrete containing perlite weighs 50 to 80 pcf. Use this for an insulating material.

(4) *Vermiculite.* Concrete with vermiculite aggregates weighs 35 to 75 pcf. Use this for insulating material.

3. HEAVYWEIGHT AGGREGATE CONCRETE. Dense concrete weighing from 200 to 360 pcf shall be mixed using the following aggregates: limonite, barytes, magnetite, steel punchings, steel sand, ferrophosphorus, or boron additives. With the exception of ferrophosphorus, these aggregates do not affect the strength of the concrete. Ferrophosphorus is expensive and slow setting. Use the same allowable stresses as for normal weight concrete, provided the aggregates do not contain substances that retard setting of the concrete.

4. CORAL-AGGREGATE CONCRETE. Coral-aggregate concrete consists of two classes: Class 1 coral aggregates are sharply angular, denserock pieces of hard reef coral that resemble pieces of limestone; class 2 coral aggregates, known as finger coral, are light, fragile, and porous. Finger coral makes an inferior concrete, with extensive honeycomb, which is low in strength and difficult to place. Avoid the use of finger coral to make first-class concrete, unless the material is determined to be exceptionally good by preliminary tests. The allowable stresses shall be computed in the same manner as for normal concrete.

a. Aggregate Weights. Class 1 aggregates 'eigh 75 to 90 pcf and class 2 aggregates weigh 65 ɔ 75 pcf in loose volumes.

b. Application. Uses of class 1 and class 2 ggregates are listed:

(1) Class 1. Use the hardest grades of lass 1 aggregates for pavements, floors, and olumns, where abrasion resistance and strength re important.

(2) Class 2. Use class 2 aggregates for ɔundations or floors in small temporary structures 'here strength and durability are secondary.

. **AIR ENTRAINED CONCRETE.** Use air en-'ained concrete for pavements in cold climates and ɔr other structures subjected to alternate cycles of 'eezing and thawing, or attack by deicing salts. ir entrained concrete is workable, has less tendency ɔ segregate than most other concretes, is durable, nd is well suited for thin sections, either precast r cast-in-place. Air entraining may be accomplished y use of patented chemicals or by use of an air en-'aining cement (for example, types IA and IIA in ac-ordance with ASTM Specifications SSC-192 and SC-197).

. **JOINTS.** Provision for expansion joints, con-'ol joints, and construction joints shall be in ac-ordance with the requirements specified as follows.

a. Expansion Joints. Expansion joints shall e provided in buildings and retaining walls.

(1) Expansion Joints in Buildings. Expan-ion joints should extend from the top of the build-ıg foundation through the roof to the top of the arapets. Each expansion joint should be in one ertical plane through walls, roof, and floors. Spe-ific rules cannot be made to govern the necessity ɔr expansion joints or their proper spacing. The ɔllowing should be considered, however: tempera-ıre differential (TD), defined as the greater of the ifferences between the annual mean air temperature nd the highest and lowest air temperature to be xpected; changes in atmospheric moisture; building hape, and possible differential settlement between djoining building areas.

(2) Guidelines for Use of Expansion Joints. 'he use of expansion joints should be in accord-nce with the guidelines specified as follows.

(a) Where the TD is not greater than 0°F and no excessive change in atmospheric moisture (such as may be expected in parts of the tropics) is anticipated, expansion joints should be spaced so that straight lengths of building measure no more than 300 feet between joints.

(b) Where the TD is greater than 70°F, or where excessive change in atmospheric moisture is likely, expansion joints should be spaced so that straight lengths of building measure no more than 200 feet between joints.

(c) An expansion joint is usually required between adjoining building areas which are different in shape, or between areas where different rates of building settlement are anticipated.

(d) Joints should be located at junctions in L-, T-, or U-shaped buildings and at points where the building is weakened by large openings in the floor construction, such as light wells, stairs, and elevators.

(3) Expansion Joints in Retaining Walls. Retaining walls are subject to extreme temperature and moisture changes, necessitating a closer spacing of joints than is required in other structures. It is standard practice to space expansion joints in retaining walls not more than 100 feet apart.

b. Control Joints. Provide control joints to limit and conceal cracks as follows:

(1) In walls with openings, space the control joints at 20-foot intervals; in walls with infrequent openings, space at 25-foot intervals.

(2) Provide a joint within 10 or 15 feet of a corner.

(3) Where steel columns are embedded in the walls, provide joints in the plane of the columns.

(4) If the columns are more than 25 feet apart, provide intermediate joints.

(5) Extend joints from the top of footing on the outside of the wall up to, over, and down back of parapet. On the inside face of the wall, the joint shall extend from floor to ceiling.

c. Construction Joints. In walls, locate horizontal joints at the floor line and vertical joints at pilasters where joint edges would not be noticeable. Locate construction joints in midspans of floor slabs or beams, or at other points of minimum shear.

7. **TILT-UP SLABS AND WALLS.** Use tilt-up slabs and walls for one-story industrial- and commercial-type buildings. For design methods, joints, reinforcement, and other details, see *Tilt Up Construction,* PCA. (See Criteria Sources.)

8. **FIRE PROTECTION.** See *Fire Protection Engineering,* NAVDOCKS DM-8, for requirements for fire protection.

9. **CLIMATIC INFLUENCES.** The climatic effects of cold regions and tropical regions on concrete are as follows.

a. **Cold Regions.** See *Cold Regions Engineering,* NAVFAC DM-9.

b. **Tropical Regions.** Spacing of expansion joints in tropic areas should be based upon consideration of moist variation as well as temperature changes.

(1) Construction Details. Careful control of materials, mixes, and construction operations is required.

(2) Cover Requirements. Concrete cover over reinforcement shall be as follows:

Item	*Cover (inches)*
Slabs	2
Beams and girders	2½
Exterior walls	1½

(3) Foundation Depth. Set bottom of foundations below level of seasonal moisture change.

10. **WATERPROOFING.** Provision for waterproofing shall be as follows.

a. **Walls Below Grade.**

(1) Foundation only – none.

(2) Around excavated spaces in use (where water is present) consider degree of protection required. Provide protective mortar covers with either bituminous membrane or metallic waterproofing, or bituminous coating as appropriate. Construction details should be consistent with waterproofing treatment.

b. **Floors, Hydrostatic Pressure.** Use foundation drains and protective covers with either bituminous membrane or metallic waterproofing. Provide structural capacity to resist hydrostatic forces.

11. **SHEAR TRANSFER.**

a. **Combined Action.** The combined action of flexible and rigid shear connectors shall not be considered as providing simultaneous shear transfer. Rigid shear connectors shall include keys, roughened surfaces, and structural shapes. Flexible connectors include stirrups, dowel bars, studs, and spirals.

b. **Separation Forces.** Provision shall be made for separation forces (between piles) as described in Chapter 7.

c. **Allowable Stresses.** Allowable stresses shall be:

(1) Shear on horizontal keys: $0.15\ f'_c$.

(2) Shear on shear connectors in composite concrete-steel system (studs, spirals, and shapes) is outlined in Chapter 7.

d. **Allowable Shear Loads on Dowels.** Allowable shear loads shall be as follows:

Reinforcing bar no.	*Shear (pounds)*
4	750
5	1,000
6	1,500
7	2,000
8	2,500
9	3,000

Section 4. DESIGN OF CONCRETE MIXES

1. **REQUIREMENTS.** Proportions of cement, water, and aggregates for normal, air entrained and coral aggregate concretes shall be within the limits specified in NAVFAC Specification 13Y (latest revision).

2. **ADDITIONAL INFORMATION.** The following standards contain additional information on design of concrete mixes.

a. **American Concrete Institute.** *Recommended Practice for Selecting Proportions for Concrete* (ACI-613); *Winter Concreting* (ACI-604); *Recommended Practice for Hot Weather Concreting* (ACI-

605); *Recommended Practice for Selecting Proportions for Structural Lightweight Concrete* (ACI-613A). (See Criteria Sources.)

b. Portland Cement Association. *Design and Control of Concrete Mixes.* (See Criteria Sources.)

c. Others. Other standards containing additional information are:

(1) *Physical Properties of Lightweight-Aggregate and Sand-Gravel Concretes.* (See Criteria Sources.)

(2) *Concrete Manual* (Bureau of Reclamation). (See Criteria Sources.)

3. MATERIALS.

a. Cement. Portland cement conforming to Federal Specification SS-C-192 shall be used as follows: type I for normal concrete and cement plaster; type II for waterfront structures in contact with sea water; type III where high early strength is needed (not to be used for waterfront structures); and type V for subsurface harbor structures. Portland-pozzolan cement (Federal Specification SS-C-208) should not be used in coral concrete as it requires rigid control and low slumps. Aluminous cement, such as lumite, can be used only where exceptionally high early strength concrete or grout is required. Oriental brands (Ube, Asano, Osaka, Kogyo, Iwaki, Onada, Taiwan, Nidon, and Chichibu) previously have been found satisfactory; however, before using, they should be tested to determine compliance with Federal Specification SS-C-192.

b. Concrete. It is essential that concrete exposed to sea water and to moist salt-laden atmosphere be as dense and impervious as practicable to preclude entrance of moisture and consequent corrosion of embedded steel and spalling of the concrete. Dissimilar metals shall not be embedded in concrete where porous aggregates, salt, or brackish mixing water are used. Investigation has shown that the principal cause of deterioration is corrosion of the steel reinforcing or conduit, and that the most important contributory factor is the unusually high porosity of the aggregates used in the concrete, which permits moisture in the atmosphere to penetrate the concrete wherein corrosion of the underlying steel takes place.

c. Aggregates. Aggregates shall conform to the requirements of NAVFAC Specification 13Y and should be from sources which provide the maximum hardness and specific gravity, preferably above 2.50, if available. High porosity aggregates should be avoided whenever possible. Aggregates should be washed clean of dust and impurities, properly graded, and stockpiled to prevent contamination and to permit an accurate determination of moisture content at time of mixing.

d. Fine Aggregate. In the Marianas area, fine aggregate for coral aggregate concrete should be manufactured from coralline limestone supplemented, if necessary, with natural sand from the Harmon Field pit, or its equivalent. All material shall be from approved sources. Based on experience on Guam, natural and manufactured sands should be blended in proportions such that the final gradation will be within the following limits:

Sieve size	*Percentage by weight passing square mesh laboratory sieves*
3/8 inch	100
No. 4	95-100
No. 8	70-90
No. 16	50-70
No. 30	30-50
No. 50	15-30
No. 100	5-20
No. 200	0-10

The aggregate shall be free from material which might react harmfully with alkalies in the cement.

e. Coarse Aggregate. In the Marianas area, coarse aggregate for coral aggregate concrete should be manufactured from coralline limestone obtained from approved sources. The abrasion loss shall be not more than 40 percent. Coarse aggregate (nominal size 1½ inches to No. 4) should be in two separate sizes: No. 4 to 3/4 inch and 3/4 inch to 1½ inches. For nominal size, 1 inch to No. 4 should be in two separate sizes: No. 4 to ½ inch and ½ inch to 1 inch. Coral aggregate should be washed after crushing to assure that the matrix of the cement paste will bond properly with the aggregate particles. To reduce

segregation, the processed aggregate should be stockpiled not higher than 6 feet.

f. Mixing Water. Mixing water should be clean and free of impurities. If fresh water is not available, salt or brackish water may be used, subject to approval of the NAVFAC Field Divisions or OICC's. Information on the use of salt water is available in NAVFAC Specification 13Y; the same limitations should apply to brackish water.

g. Additives ond Admixtures. The proper uses of admixtures and additives require that the following be noted:

(1) Admixtures include air entraining agents as well as agents to improve workability, to accelerate or retard setting, and to reduce the water content. These admixtures can be used to achieve desired characteristics in the concrete, but not to correct inherent deficiencies or to replace normal practice. Proper use of admixtures can produce an economical mixture for cement.

(2) To insure proper curing and crack-free, impervious concrete, a membrane curing compound should be used whether or not admixtures have been added.

h. Proportioning. Weight proportioning is preferable in all areas where local conditions and available equipment permit. Extreme variations, such as specific gravity, moisture content, and so on, can make weight proportioning impracticable. In some areas it may be necessary to vary the cement factor; for example, in the Marianas, the cement factor for each class specified in Table 1 (NAVFAC Specification 13Y) should be 0.5 bag per cubic yard lower. In areas where porous aggregate, salt water, or brackish water is used, a minimum cement content of seven bags per cubic yard is recommended.

i. Grouting Mortar. A mixture of one bag of Portland cement, 2 cubic feet of well-graded, fine aggregate, 1 teaspoon of aluminum powder, and enough water to provide a maximum water-cement ratio of 0.50 by weight are used for the nonshrinking type of grouting mortar. In lieu of this mixture, an approved standard commercial grouting mortar containing a metallic chemical oxidizing agent may be used. The approved product shall be delivered to the site of the work in the original sealed containers, each bearing the trade name of the material and the name of the manufacturer. Surfaces to receive the mortar shall be clean, and shall be moistened thoroughly immediately before placing the mortar. Exposed surfaces of mortar shall be water-cured with wet burlap for 7 days. Before grouting, the top of each concrete footing shall be roughened and cleaned thoroughly, all loose particles shall be removed, and the surface flushed thoroughly with neat cement grout immediately before the grouting mortar is placed.

CHAPTER 4. TIMBER STRUCTURES

Section 1. SCOPE AND RELATED CRITERIA

1. **SCOPE.** Criteria, as presented herein, are necessary for the design of structural elements of timber, including allowable stresses and detailed design considerations.

2. **RELATED CRITERIA.** Certain criteria related to timber structures appear in other chapters of this design manual and in other manuals in the design manual series, as follows:

Subject	*Source*
Termite control	NAVDOCKS DM-1
Fire protection	NAVDOCKS DM-8
Service classifications	Chapter 2
Waterfront structures	NAVFAC DM-25

3. **CLASSIFICATION.** Timber structures are classified as follows:

(1) Structures framed of stress-grade lumber.

(2) Structures framed of nonstress-grade lumber.

(3) Structural laminated construction (including plywood and glue laminated types).

4. **SELECTION OF TYPE OF CONSTRUCTION.** Selection factors for type of timber construction are listed in Table 4-1.

5. **SELECTION OF SPECIES OF TIMBER.** Selection factors for species of timber are contained in Table 4-2.

Section 2. ALLOWABLE STRESSES

Part 1. GENERAL

1. **STANDARD GRADES.** Allowable stresses for the various grades of timber and appurtenant fasteners, including connectors, bolts, screws, and nails, shall be as given in the standard specifications cited in this chapter.

2. **OTHER GRADES.** For allowable unit stresses for species and grades of lumber not given in the standard specifications, see *American Lumber Standards, Simplified Practice, Recommendation R16-53,* U.S. Department of Commerce and *Methods of Establishing Structural Grades of Lumber D245-49T,* ASTM. (See Criteria Sources.) For normal loading conditions, use 110 percent of the values in columns 2, 3, 4, and 5, Table VIII of ASTM D245.

3. **SERVICE CLASSIFICATIONS.** As are steel structures, timber structures shall be classified into classes A, B, and C. (See Chapter 2.)

Part 2. STRESS-GRADE LUMBER

1. **STANDARD SPECIFICATIONS.** Allowable stresses for stress-grade lumber used in class A structures shall conform to the requirements of the AASHO Standards and AREA Specifications (see Criteria Sources) cited in Chapter 2. For allowable stresses for stress-grade lumber used in classes B and C structures, see the *National Design Specification for Stress-Grade Lumber and Its Fastenings,* National Forest Products Association (NFPA) (see Criteria Sources), except as modified in Table 4-3 and Figure 4-1. Allowable stresses for stress-grade lumber pressure impregnated with fire-retardant chemicals shall be reduced by 10 percent. The energy absorbing capacity of blast-resistant structures constructed of lumber pressure impregnated with fire-retardant chemicals shall be reduced by 30 percent.

Part 3. NONSTRESS-GRADE LUMBER

1. **APPLICATION.** Nonstress-grade lumber may be used for joists, rafters, studs, miscellaneous

TABLE 4-1

Selection Factors for Type of Timber Construction

Factor	Requirement	Factor	Requirement
General	Except where there will be much duplication of members, use of full size (rather than built-up) members is usually economically desirable.	Exposure (Continued)	4. Some species of hardwoods are resistant to decay and insects. (See nondomestic timbers.)
Size of member	1. Where required depth and width exceed sizes locally available (normally 16 to 20 in.), use built-up construction (glue laminated or plywood). 2. Where required length exceeds length locally available and splicing is inconvenient or undesirable, use built-up construction. 3. Use of small size (section and length) pieces is economically desirable. Trussed rafters and built-up sections are particularly desirable in this regard. The lamella arch may also be considered.	Architectural considerations	See Table 5-11, NAVDOCKS DM-1.
		Duplication and offsite construction	Where there will be much duplication of members, use of built-up sections of trussed rafters may be considered. Adoption of built-up sections permits use of variable sections and various grades of lumber.
		Shape	Built-up sections may be used where proposed cross section or elevation of the member is to be other than rectangular.
		Plant	When considering use of glue laminated construction, a plant must be available locally or shipping charges shall be considered from available plants.
Exposure	1. Plywood, built-up members are normally limited to use in locations not directly exposed to weather (edges are damaged by moisture). However, exterior grades are available if needed. 2. Glue laminated constructions and solid full-size members may be used for exterior exposures. 3. Glue laminated has good resistance to moisture and biologically destructive agents.	Spans	1. Short spans: Rafters 2. Intermediate spans: Trussed rafters Trusses Glue laminated 3. Long spans Trusses Glue laminated Arches Built-up

framing, and other members not carrying computed stresses. Do not use in members requiring connector rings in joints.

2. **GRADES.** Grades on nonstress-grade lumber for various uses shall conform to the requirements of NAVFAC Specification 28Y (latest revision).

3. **DESIGN.** Tabulated data on sizes, spans, and spacing of nonstress-grade lumber used as joists and rafters for interior applications are contained in *Wood Structural Design Data* – Vol. 1, NFPA. (See Criteria Sources.) For other applications or for spans and loads not considered in these tables, members of nonstress-grade lumber shall be proportioned for working stresses of 1,000 psi for flexure and 800 psi for compression, with no increase for duration factors.

Part 4. STRUCTURAL LAMINATED CONSTRUCTION

1. TYPES.

a. **Glue Laminated.** A structural element comprised of sawed wood laminations bonded together with adhesives; the grain of all laminations is approximately parallel longitudinally.

b. **Mechanically Laminated.** A structural element comprised of laminations which are not glued

TABLE 4-2
Selection Factors for Species of Timber

Factor	Requirement	Criteria source
Local availability	Where feasible select a species available locally.	
Size	Check commercial availability of desired sizes (including length).	
Strength (stress-grade)	Criteria for selection of stress grades are similar to those applicable to selection of class of concrete or type of steel (See criteria in individual Design Manuals.).	
Workability	Good workability is of minor importance for solid section timbers, but is desirable for built-up members.	For relative workability of several species, see Tables 10 and 11 of *USDA Wood Handbook.*
Decay resistance	Where conditions warrant, decay-resistant lumber should be selected.	For relative decay resistance of several types of wood, see *USDA Wood Handbook.*
Weathering	Exposed boards should be of a species having good weathering qualities.	For weathering characteristics of boards of several species, see *USDA Wood Handbook.*
Other		For other properties of various species and principle uses, see *USDA Wood Handbook.*

but are held together with mechanical fastenings such as nails or bolts; the grain of all laminations is approximately parallel longitudinally.

c. Plywood. A wood element in which plies are bonded together with adhesives; the grain of each ply is not parallel to the grains of adjoining plies.

d. Glued, Built-Up. A structural element consisting of wood, plywood, or a combination of the two, in which the grains are not necessarily parallel; all pieces are bonded together with adhesive.

2. STANDARD SPECIFICATIONS. For collateral reading on the subject, see *Fabrication and Design of Glue Laminated Wood Structural Members*, U.S. Department of Agriculture (USDA) TB No. 1069 and AITC Standard Specifications (Bibliography).

a. Glue Laminated Members. For class A structures, allowable stresses shall conform to the requirements of the AASHO Standards and AREA Specifications. (See Chapter 2.) For classes B and C structures, allowable stresses shall conform to the requirements of the NFPA Specification.

b. Mechanically Laminated Members. Allowable stresses for individual pieces used in mechanically laminated members shall comply with those established for sawed members. (See Part 2.)

c. Plywood Members. For classes B and C structures, allowable stresses shall conform to the requirements of Table 37 of *Wood Handbook,* USDA (see Criteria Sources) using basic allowable stresses as given in the NFPA Specifications. Allowable stresses for class A structures shall be 90 percent of the values for classes B and C structures. Allowable stresses for plywood treated with fire-retardant salts shall be reduced by the following percentages:

Property	*Percent reduction*
Modulus of elasticity (E)	10
Modulus of rupture (G)	20
Ultimate load (U)	20

d. Glued, Built-Up Members. Allowable stresses for individual components (whether plywood or sawed lumber) shall conform to the requirements indicated previously.

Part 5. NONDOMESTIC MEMBERS

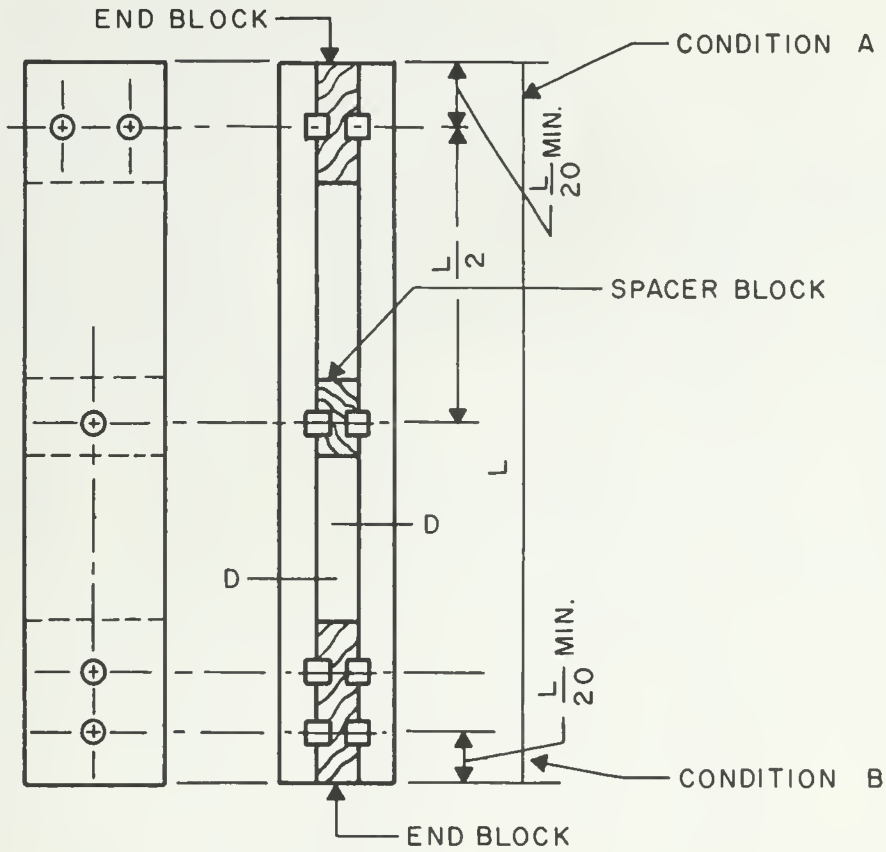
1. FACTORS AND STRESSES. Many nondomestic species of timber are suitable for construction work. Some have very high strength, durability, and resistance to attack by marine borers.

TABLE 4-3

Modifications to the National Design Specifications for Stress-Grade Lumber and Its Fastenings (NFPA)[1]

Section	Modification	Section	Modification
101-B	Add at the end of the sentence: "for the required load and erection stresses."	301-B-2	Earthquake and other forces (including ice loads and longitudinal loads) for design purposes shall conform to the requirements of Chapter 1 of this Design Manual.
200-C	Add the following paragraph: "The minimum dressed sizes (green) of structural lumbers to be used in design computations shall be based on the following: Beams and stringers. Nominal thickness, 5 or more inches; nominal widths, 8 or more inches; standard sizes, SIS, SIE, S2S, or S4S, ½ inch off each way. Joists and planks. Nominal thicknesses, 2 inches to, but not including, 5 inches; nominal widths, 4 or more inches; standard thicknesses, SIS or S2S, ⅜ inch off; standard widths, SIE or S2E, 4 inches, ⅜ inch off, and 6 inches or more wide, ½ inch off. Posts and timbers. Nominal sizes, 5 by 5 inches and larger; standard sizes, SIS, SIE, S2S, or S4S, ½ inch off each way. Rough lumber should be sawed to full nominal dimensions, except that occasional slight variation in sawing is permissible.	302-A	Delete this paragraph and substitute "Design live loads shall conform to the requirements of Chapter 1."
		401-B-2	Substitute Figure 4-1 for Figure 3 of NLMA.
		401-F-5	At the end of this paragraph, add the following: "In no case shall the L/b ratio exceed that for L/d."
		403-D	At the end of the paragraph, add the words: "and shall be used wherever f_c is greater than or equal to f_b."
		500-L-5	Insert: "End distances for splice pads in tension shall be 12 inches minimum."
		600-C-2	Add: "Threads of bolts shall be long enough to permit tightening required by shrinkage of lumber."
		801-A	Add 801-A-2: "No withdrawal resistance shall be considered for drift pins or drift bolts driven into end grain of timber."
200-C	No shipment should contain more than 20 percent of pieces of minimum dimension due to such variation in sawing. In any one shipment, at least 80 percent of the pieces should be of full nominal dimensions, and the remainder should be not more than one-sixteenth inch scant."	Appendix F, Section E	Add: "The camber provided by the formula is for simply supported trusses built of seasoned lumber with bolted joints or connector joints. For green lumber, the camber provided by the formula should be increased 50 percent. For continuous trusses the corresponding cambers for end and interior spans shall be taken at 75 percent of the simple span camber for the end spans and 50 percent for the interior spans. Camber shall be provided by changing the lengths of the web members."
203 and 500	1. In Paragraph 203-A and 500-C-3, add the sentence: "Increases in allowable unit stresses for intermediate durations of load, not tabulated, may be obtained by interpolation." 2. Add paragraph 203-B and 500-C-3A as follows: "203-B - 500-C-3A. The provisions of Chapter 1 of this Design Manual relating to increased allowable stresses in various load combinations shall not apply for timber structures and their connectors. These increases in allowable stress shall be additive to the increases given in paragraph 203A and 500-C-3.	Appendix F, Section J-1	For the last sentence, substitute: "Where sheathing other than wood is used and which cannot be considered as supporting the purlins, lateral bracing should be installed."
		Appendix F, Section J-2	Add: "The above shall be deemed minimum requirements. Bracing shall be proportioned for computed lateral loads and location shall be governed by arrangement of principal framing. "The limitations for l/d of bracing in compression shall be the same as for columns. "Bracing in tension and bracing carrying no computed stress shall have an l/d not in excess of 80."
205-C	Add: "Such members shall be marked on the drawings with 'M' for members continuous over two spans and with 'N' for members continuous over three or more spans." (See NAVDOCKS DM-6.)		

[1] National Forest Products Association



CONDITION A

WHEN THE MEMBERS ARE JOINED TOGETHER AT EACH END BY ONE OR MORE RINGS LOCATED ON A LINE TRANSVERSELY (ACROSS THE FACE), AND THE END DISTANCE IS NOT LESS THAN $\frac{L}{20}$.

L = OVERALL UNSUPPORTED LENGTH IN INCHES FROM CENTER TO CENTER OF LATERAL SUPPORTS OF CONTINUOUS SPACED COLUMNS AND FROM END TO END OF SIMPLE SPACED COLUMNS.

$\frac{L}{2}$ = DISTANCE FROM CENTER OF CONNECTORS IN END BLOCKS TO CENTER OF SPACER BLOCK.

D = DIMENSION IN INCHES OF LEAST SIDE OF INDIVIDUAL MEMBER.

CONDITION B

WHEN THE MEMBERS ARE JOINED TOGETHER AT EACH END BY TWO OR MORE RINGS LOCATED LONGITUDINALLY (ALONG THE LENGTH OF THE MEMBER), AND THE END DISTANCE OF THE FIRST CONNECTOR IS NOT LESS THAN $\frac{L}{20}$.

FIGURE 4-1
Spaced Column-Connector Joined

a. Selection Factors. Selection of nondomestic species is a matter of economics. Consider the use of smaller sections resulting from higher strength of these species, increased resistance to deterioration, and resistance to borers. Some of the harder woods are particularly adaptable for fender systems. There is a partial listing of nondomestic hardwoods and their properties in Table 4-4.

(1) Pressure preservative treated Apitong (*Dipterocarpus grandiflorus blanco*) is highly suitable for wood piling and utility poles.

(2) The tropical woods Ifil (*Intsia bijuga*), Daog or Palomara (*Calophyllum inophyllum*), Ahgao

TABLE 4-4

Properties of Nondomestic Species of Timber

Region	Name	Bending strength	Hardness	Shock resistance	Specific gravity	Durability	Marine borer resistance	Availability
British Guiana	Greenheart	Very strong	Very hard	Good	0.93	Good	Fair	Abundant
French Guiana	Angelique	Strong	Hard	Good	0.72	Good	Fair	Fair
Brazil	Piquia	Strong	Hard	Good	0.88	Good	Fair	?
British Guiana	Maristribaili	Very strong	Very hard	Good	1.09	Excellent	Excellent	?
South America	Acapu	Strong	Hard	Good	0.95	Good	Good	Fair
British Guiana	Black Kakeralli	Strong	Very hard	Good	1.00	Excellent	Excellent	?
Western Pacific Region	Atoeng	Strong	Hard	Good	0.83	Good	Good	Fair
Western Pacific Region	Ipil	Very strong	Very hard	Good	0.78	Good	Good	Limited
Western Pacific Region	Kasi-Kasi	Fair	Hard	Good	0.61	Good	Very good	Fair
Western Pacific Region	Dungon-late	Strong	Hard	Good	1.01	Good	Very good	Fair
Western Pacific Region	Pagatpat	Strong	Hard	Good	1.03	Good	Good	Fair
Western Pacific Region	Tongong	Strong	Hard	Good	0.99	Good	Good	Fair
Western Pacific Region	Bogoia	Strong	Hard	Good	1.14	Good	Very good	Plentiful
Philippine Islands	Anubing	Fair	Moderate	Good	0.75	Good	Very good	Fair
Philippine Islands	Alupag	Strong	Hard	Fair	0.97	Very good	Good	Limited
Philippine Islands	Apitong	Strong	Hard	Good	0.80	Creosoting recommended		Plentiful
Philippine Islands	Bansalagin	Strong	Very hard	Good	1.06	Good	Fair	Fair
Philippine Islands Philippine Islands	Kalamansanai	Strong	Very hard	Good	0.93	Fair	Fair	Fair
Philippine Islands and New Guinea	Narig	Very strong	Very hard	Good	0.97	Good	Very good	Fair
New Britain and New Guinea	Komo Kamarere	Strong	Hard	Good	0.83	Good	Fair	Fair
New Britain and Bismarck	Malasa	Strong	Hard	Good	0.97	Good	Good	Fair
New Britain and Moluccas	Zizanu	Good	Hard	Good	0.75	Good	Good	Plentiful
South Papua	Paper-bark	Strong	Very hard	Fair		Good	Good	Abundant
South China Sea Region	Kiet-mouk	Strong	Hard	Good	0.97	Good	Fair	Fair
South China Sea Region	Doengon	Strong	Hard	Good	1.01	Good	Fair	Fair
South China Sea Region	Seng Kang Wang	Strong	Very hard	Good	1.04	Very durable	Good	Fair
South China Sea Region	Bakau-belukap	Strong	Hard	Good	0.99	Durable	Good	Plentiful
South China Sea Region	Baratlaut	Very strong	Hard	Good	1.11	Very durable	Good	Fair
South China Sea Region	Balam sundik	Strong	Hard	Good	0.77	Very durable	Good	Fair
East Indies	Moluccan Ironwood	Strong	Very hard	Good	0.77	Good	Fair	Fair
Thailand	Deng	Very strong	Hard	Good	1.10	Good	Good	Plentiful
Thailand	Lumpaw Maca-mong	Very strong	Hard	Good	0.77	Good	Good	Plentiful
Thailand	Kleng	Strong	Hard	Good	0.90	Good	Good	Fairly plentiful

TABLE 4-4 (Continued)

Properties of Nondomestic Species of Timber

Region	Name	Bending strength	Hardness	Shock resistance	Specific gravity	Durability	Marine borer resistance	Availability
Thailand	Rang	Strong	Hard	Good	0.99	Good	Good	Plentiful
Thailand and Burma	Teng	Strong	Hard	Good	1.04	Good	Good	Plentiful
Malaya and Burma	Kojoe Batoe	Strong	Hard	Good	0.98	Durable	Good	Fair
Burma	Pyinkado	Strong	Hard	Good	0.95	Very durable	Good	Abundant
Borneo	Lizerhout	Very strong	Very hard	Good	1.03	Very durable	Good	Fair
Nepal	Sal	Strong	Very hard	Good	0.90	Durable	Good	Fair
Nepal	Sandan	Strong	Hard	Good	0.89	Durable	Fair	Fair
Nepal	Dhaura	Strong	Hard	Good	0.92	Durable	Fair	Fair
East Pakistan	Chaplash	Fair	Fair	Good	0.65	Durable	Very good	Fair
East Pakistan	Nageswar	Very strong	Very hard	Good	1.02	Very durable	Good	Fair
West Africa	Ekki	Very strong	Very hard	Good	0.97	Very durable	Very good	Plentiful
West Africa	KoKrodua	Strong	Hard	Good	0.70	Very durable	Good	Plentiful
Australia	Jarrah	Strong	Hard	Good	0.80	Very durable	Good	Plentiful
Australia	Ironbark	Very strong	Very hard	Good	1.10	Very durable	Good	Plentiful

(*Premna obtusifolia*), Fago (*Ochrosia oppositifolia*), Yacal (*Hopea, Shorea,* and *Isoptera* species), Molave (*Vitex parviflora Juss*), and Chopag (*Ochrocarpos odoratus*) are satisfactory for most structural uses. Redwood should be used structurally only in cooling towers.

(3) The following local tropical woods, on Guam, should be used only when construction is to be of a temporary nature: Coconut (*Cocus nucifera*), Dugdug (*Artocarpus sp.*), Nunu (*Ficus prolixa*), *Yoga* (*Elacocarpus joga*), and Faya (*Tristiropsis obtusangula*).

b. Allowable Stresses. Strength properties of individual species should be obtained from the potential supplier. Working stresses should be one-fourth to one-third of the ultimate strengths. The designer should consider characteristics as published by suppliers with caution and should insist on tests of random specimens to verify assumed strength characteristics.

2. STANDARD SPECIFICATION. See Military Specification MIL-L-22626 for Azobe (*Ekki*), a West African hardwood.

Section 3. DESIGN STANDARDS FOR TIMBER STRUCTURAL ELEMENTS

1. STRESS-GRADE LUMBER. Design standards and provisions for structural elements of stress-grade lumber used in class A structures shall conform to the requirements of the AASHO Standards and AREA Specifications. (See Chapter 2.) Design standards and provisions for structural elements of stress-grade lumber used in class B and C structures shall be in accordance with the NFPA Specification, except as modified in Table 4-3, and subject to the following provisions.

a. Sealers. Where feasible, minimize seasoning checks in the ends of timber pieces installed in an unseasoned condition by the use of end coating or sealers.

b. Connections. Connections shall be detailed to permit periodic tightening.

c. Hardware. Bolt holes for drift bolts shall be bored with a bit having a diameter 1/8 inch less

than the bolt diameter. Screws should be lubricated before insertion. The length of embedment shall not exceed that required to develop the tensile strength of the screw, based on root of thread diameter. The necessary length to develop such tensile strength is about 7 times the diameter of the shank in hard woods, and 10 to 12 times the diameter of the shank in softer species.

2. NONSTRESS-GRADE LUMBER. Design standards, procedures, and provisions shall conform to the requirements for stress-grade lumber.

3. STRUCTURALLY LAMINATED LUMBER.

a. Glue Laminated Members. Design standards, procedures, and provisions for class A structures shall conform to the requirements of the AASHO Standards and AREA Specifications. Design standards, procedures, and provisions for classes B and C structures shall conform to the requirements of the NFPA Specification.

b. Mechanically Laminated Members. Design standards and procedures shall be the same as for components formed from sawed lumber. Loads in connectors for all classes of structures shall conform to the requirements of the NFPA Specification. In vertically laminated beams where spikes are used, provide through bolts or bolts with connectors to prevent separation of the planks. Place two bolts at each end of the beam to hold the ends together. Transverse joints in the planks shall not be considered as transmitting any stress.

c. Plywood Members. Design standards, procedures, and provisions shall conform to the requirements of "Plywood and Other Crossbanded Products," *Wood Handbook*, USDA (see Criteria Sources) and as supplemented in the *Technical Data Handbook*, Douglas Fir Plywood Association (DFPA). (See Criteria Sources.) Design provisions, other than allowable stresses, in this publication shall be considered applicable to plywood manufactured from materials other than Douglas Fir, the allowable stresses conforming to the provisions of Section 2.

(1) Built-Up Plywood Girders.

(a) Allowable shear stress between flanges and web shall not exceed 0.375 time allowable stress in horizontal shear.

(b) Web stiffeners shall be screwed to webs and in contact with both flanges. The thickness shall be at least 6 times the thickness of the web, or 160 times the outstanding leg, with a minimum of 3/8 inch. Stiffeners shall be as wide as the flange. Spacing shall be equal to or less than two times the clear distance between flanges.

(c) Provide wood blocks (bearing stiffeners) at points of concentrated load or bearing, or both.

(d) For deep girders, reduce the allowable stresses to account for the lack of lateral support of the center fibers as compared to the flange fibers. See *Technical Data Handbook*, DFPA. (See Criteria Sources.)

(2) Stressed-Skin Panels.

(a) For effective flange width, see *Technical Data Handbook*, DFPA. (See Criteria Sources.)

(b) In bending, tension, and compression, consider only those plies where the grain is parallel to the span.

d. Glued, Built-Up Members. Design standards, procedures, and provisions for individual components (whether plywood or sawed lumber) shall conform to the requirements for such components as previously indicated, except as follows.

(1) Transverse Joints. Transverse joints in the planks may be considered as transmitting stress if scarfed joints having a slope not steeper than 1:10 are used. Joints shall be spaced not less than 24 times the lamination thickness in areas of maximum stress. In lesser stressed areas, spacing may be reduced linearly in proportion to relative stress. Butt joints shall not be used for structural members.

(2) Glue Laminated Members. Fabrication of glue laminated members, the types of adhesives, and their application shall conform to the requirements of *Fabrication and Design of Glue Laminated Wood Structural Members*, USDA TB No. 1009. (See Criteria Sources.) The type of glue shall be specified in the contract.

(3) Mechanical Fasteners. Mechanical fasteners shall not be used in conjunction with glued construction. The movements required to develop the mechanical fasteners are inconsistent with those permitted in glued joints.

(4) Quality Control. There is no way to control the quality of glue laminated fabrication,

other than by personal inspection and observation of the techniques. Plant inspection must be provided for glue laminated designs, except for minor components.

4. **NONDOMESTIC TIMBERS.** Design standards and procedures for nondomestic timbers shall be as specified for domestic species (NFPA Specification and USDA *Wood Handbook*). (See Criteria Sources.)

Section 4. SPECIAL REQUIREMENTS

1. **WOOD PRESERVATION.** Preservative treatment for wood should be performed prior to construction and, preferably, after fabrication. The use of treated timbers is recommended under the following circumstances and subject to the following conditions.

a. Direct Ground Contact. Creosote the wood in accordance with the requirements of the American Wood Preservers Association (AWPA).

b. Exposure to Weather. Items such as decks of loading platforms, bumper rails, steps, fire ladders, handrails, tent floors, sashes and frames, and similar items which are subject to decay and are exposed to the weather should be pressure treated with waterborne salts or oilborne preservatives in volatile solvents. After evaporation of the water or the volatile solvent carrier, these wood items may be painted. All cut surfaces of pressure treated lumber should be liberally swabbed with a solution of the preservative with which the wood has been impregnated.

c. Structural Framing. Pressure preservative treatment for timber should be used under the following conditions of exposure:

(1) All wood in contact with ground or water.

(2) Wood in contact with masonry or metal, where conduction or condensation creates problems.

(3) Roof structures (framing and sheathing) installed over enclosed swimming pools, or in building structures where high humidities prevail.

(4) Areas in or near shower rooms, galleys, sculleries, laundry rooms, and cold-storage rooms.

(5) Areas of basementless buildings in close proximity to the soil, where moisture and termites can attack the structural elements.

(6) In slab-on-ground or crawl-space houses (basementless), all lumber within 18 inches of the ground should be pressure treated.

(7) In regions where dry-wood termites prevail, all structural wood members shall be pressure treated.

(8) On waterfront structures, as specified in *Waterfront Operational Facilities,* NAVFAC DM-25.

(9) Creosote or creosote solutions are not recommended where color, odor, or exudation of the preservative may be undesirable. Waterborne salts or oilborne chemicals in volatile solvents should be used under these circumstances. Cut surfaces shall be treated.

d. Site Requirements. The Naval Facilities Engineering Command and Field Divisions have entomologists on their staffs who should be consulted during the planning, design, and construction stages for information on insects at the specific site.

2. **FIRE RETARDANT TREATMENT.** Recommended practices for attaining fire resistance through construction details or chemical treatment are given in *Wood Handbook* (USDA); *National Building Code,* American Insurance Association; *NFPA Handbook of Fire Protection,* National Fire Protection Association (NFPA) (see Criteria Sources), and Military Specification MIL-F-19140. In addition, refer to *Fire Protection Engineering,* NAVDOCKS DM-8.

3. **CLIMATIC INFLUENCES.** Climatic influences for cold and tropic regions are as follows.

a. Cold Region Conditions. For cold region limitations, see *Cold Regions Engineering,* NAVFAC DM-9. Engineering properties usually are not appreciably affected when wood is subjected to extremely low temperatures.

b. Tropical Conditions. Engineering properties of wood are not appreciably affected in tropical climates. However, rot and insect attacks are aggravated in tropical humid areas, and all timber for permanent construction in tropical areas should be preservative treated, except local native hardwoods

as discussed in Section 2 of this chapter. The following provisions shall be made.

(1) Ground Contact. Members shall not be in contact with the ground. The lowest floor timbers shall be a minimum of 18 inches aboveground on posts or piers, except 24 inches for tropical-humid climates.

(2) Ventilation. All members shall be ventilated and located for rapid drying.

(3) Drainage. Wide eaves shall be provided to keep water off sides of buildings.

(4) Drying. Use of unseasoned wood in environments where rapid drying is prevented (in enclosed spaces, where encased in concrete, or painted) is prohibited.

(5) Fastening. Nails, bolts, screws, and brads should be of nonferrous material, such as tempered aluminum or high-nickel stainless steel. For Guam, cement-coated nails also can be used. Uncoated ferrous fasteners are unsatisfactory.

(6) Bonding. Structural bonding to other materials should be by means of epoxy resin adhesive (see Military Specification MIL-A-8623). Bonding of wood to wood can be made by a variety of adhesives, such as those covered by military specification MIL-A-22397 for marine or severe outdoor use and Federal Specification MMM-A-181 for general purposes.

4. TEMPORARY STRUCTURES. The design criteria for temporary timber structures shall be modified as follows:

(1) Provisions of the Standard Specifications relating to decreased allowable stresses for full load, permanently applied, shall be disregarded.

(2) The use of untreated timbers can be considered for applications normally requiring treated timbers.

5. DISTRIBUTION OF A CONCENTRATED LOAD. For bridge structures, see AASHO Specifications. For other structures, see Appendix A of the NFPA Specification.

6. DEFLECTIONS. Deflection of wood is not a function of purely elastic action. To determine deflection, use the constants and charts in *Wood Handbook*, USDA, and in *Technical Data Handbook*, DFPA. (See Criteria Sources.) When used for concrete formwork, the stiffness of the wood is decreased about 20 to 25 percent by absorption of moisture.

7. TERMITE CONTROL. See *Architecture*, NAVDOCKS DM-1, for criteria pertaining to termite control.

CHAPTER 5. ALUMINUM STRUCTURES

Section 1. SCOPE AND CHARACTERISTICS OF ALUMINUM ALLOYS

1. **SCOPE.** This chapter presents criteria relating to the structural applications of aluminum alloys.

2. **CHARACTERISTICS OF ALUMINUM ALLOYS.** The characteristics of aluminum alloys are as follows.

a. **Structural Properties.** The low modulus of elasticity in aluminum alloys requires investigations of deflection, tension, compression, and shear conditions. Investigate local and overall crippling and buckling situations.

(1) There is no clearly defined yield point. Yield stress is established at 0.2 percent permanent set. A narrow spread exists between yield and ultimate strengths.

(2) Welding heat lowers the strength of most aluminum alloys.

b. **Elastic Properties.** The coefficient of linear expansion of aluminum is about twice that of steel. However, because of a lower modulus of elasticity, stresses in aluminum alloy structures resulting from temperature changes or misalinements of parts are lower than those in steel structures.

c. **Other Properties.** Additional properties of aluminum are as follows:

(1) Light weight.

(2) Ease of workability, fabrication, and extrusion.

(3) Corrosion resistance.

(4) Low maintenance cost.

(5) Lack of spark generation.

(6) High electrical and heat conductivity.

(7) High reflectivity of light in visible and infrared wavelengths.

d. **Major Alloys.** Major aluminum alloys and their characteristics are outlined in Table 5-1.

TABLE 5-1
Structural Aluminum Alloys

Alloy	Characteristics	Uses
6061-T6	Good strength and workability. High corrosion resistance.	Bridges and heavy-duty structures, bridge railings, marine applications, pipes, and pipe flanges.
2014-T6	High strength. Moderate cost.	Bridges and heavy-duty structures.
6063-T6	Moderate strength. High corrosion resistance. Low cost.	Pipe railings, irrigation pipe, standard pipe. Use in structural elements proportioned for stiffness rather than strength.

3. **CLASSIFICATION.** Classes A, B, and C structures utilizing aluminum members shall be the same as defined in Chapter 2.

Section 2. ALLOWABLE STRESSES

1. **ALUMINUM ALLOYS.** Use specifications for structures of aluminum, *Aluminum Construction Manual,* The Aluminum Association (see Criteria Sources).

2. **MODIFICATION.** Allowable stresses for various load combinations may be increased per Chapter 1.

Section 3. DESIGN STANDARDS FOR ALUMINUM ALLOY STRUCTURES

1. **BUILDINGS, BRIDGES, AND TOWER STRUCTURES.** The basic design procedures for buildings, bridges, and tower structures are as follows.

a. Design. For design of beams, plate girders, stiffeners, columns, tension and compression members, connections, and other elements, see appropriate items in the *Aluminum Construction Manual* and *ASCE Structural Division Proceedings Papers 3341 & 3342* (see Criteria Sources) (aluminum alloys 6061-T6 and 2014-T6).

b. Design Procedures. Design procedures are contained in structural handbooks available from the aluminum companies, and in the *Aluminum Construction Manual.* (See Criteria Sources.)

2. **PIPING AND STRUCTURES FOR WATER SUPPLY AND SEWAGE.**

a. Specifications. Specifications for piping and water supply structures are contained in *Boiler and Pressure Vessel Code,* ASME. (See Criteria Sources.) Computed bursting pressures of aluminum tubes and pipes are in structural handbooks, available from several aluminum companies.

b. Safety Factors. Use a safety factor of 4 for bursting pressures. Provide increased thicknesses of tubes or pipes to allow for supports, external loads, and corrosion.

3. **LIMITED LIFE STRUCTURES.** For structures that have a life expectancy of less than 1 year, the factor of safety may be 1.50; or in cases where maximum loading conditions are known, the factor of safety may be 1.25. In the cited specifications, factors of safety for tension, compression, buckling, and so on, are given so that modifications to them may be made by proportional increases of the working stresses. For structures with a limited life expectancy, but in excess of 1 year or more, consult NAVFAC HQ for guidance.

Section 4. SPECIAL CONSIDERATIONS

1. **FIREPROOFING.** At present, suitable fire resistance rating data are unavailable for aluminum structural elements.

a. Recommendations. Where a fire resistance rating is necessary for aluminum structural members, the protection measures for steel contained in the *National Building Code*, American Insurance Association (see Criteria Sources) may be used as a guide.

b. Modifications. Where modifications are necessary, the need for such modifications and their nature should be determined in consultation with the NAVFAC Engineering Field Division's Fire Protection Engineer.

2. **FASTENINGS FOR ALUMINUM STRUCTURES.**

a. Aluminum Bolts. Aluminum bolts shall be of high strength alloys such as 2024-T4 or 6061-T6. Tighten with torque wrenches to avoid overstressing. Use molybdenum disulfide as a lubricant for threads.

b. Steel Bolts. Steel bolts shall be galvanized or cadmium plated. Use galvanized washers underneath the heads and nuts to avoid surface damage by sharp edges.

c. Stainless Steel Bolts. Precautions against corrosion for stainless steel bolts are unnecessary.

d. Rivets. For riveted joints, all faying surfaces shall be painted before assembly. One coat of zinc chromate primer shall be applied to each surface and allowed to dry before the joint is assembled.

CHAPTER 6. MASONRY STRUCTURES

Section 1. SCOPE AND MATERIAL COMBINATIONS

1. SCOPE. Design criteria, including allowable stresses and detail requirements for masonry structures, are presented in this chapter. Brick, block, and tile masonry are considered. Related constructions, such as gypsum and plastics, appear in Chapter 8.

2. COMBINATION OF MATERIALS. Allowable stresses for masonry structures are based on both the strength of the masonry unit and the strength of the mortar. For this reason, allowable stresses are stated for a combination of a given strength of masonry unit and a given type of mortar.

Section 2. ALLOWABLE STRESSES

1. PLAIN MASONRY. For allowable stresses, see *American Standard Building Code Requirements for Masonry,* "Article 4.2, Allowable Stresses," NBS; Except for brick, see *Building Code Requirements for Engineered Brick Masonry,* Article 4.3, SCPI. (See Criteria Sources.)

2. REINFORCED MASONRY. For allowable stresses, see *American Standard Building Code Requirements for Reinforced Masonry,* Article 5.5, "Allowable Stresses in Reinforced Masonry," and Article 5.6 "Allowable Stresses in Reinforcement," NBS; Except for reinforced brick masonry, see *Building Code Requirements for Engineered Brick Masonry,* Article 4.4, SCPI. (See Criteria Sources.)

Section 3. STRUCTURAL MASONRY DESIGN STANDARDS

1. STANDARD SPECIFICATIONS. For standard specifications for detail design requirements of wall thickness, wall heights, lateral support, bond, anchorage, corbelling, stress, reinforcement, and related items, see *American Standard Building Code Requirements for Masonry* and *American Standard Building Code Requirements for Reinforced Masonry,* NBS; Except for brick, see *Building Code Requirements for Engineered Brick Masonry,* SCPI.

2. PROCEDURES. Procedures and details of design are contained in *Brick and Tile Engineering Handbook of Design,* SCPI; *Recommended Practice for Engineered Brick Masonry,* SCPI; and *Concrete Masonry Handbook,* PCA. (See Criteria Sources.)

Section 4. SPECIAL CONSIDERATIONS

1. EXPANSION JOINTS.

a. Coefficient of Expansion. For values of coefficients, see Table 6-1. Additional information for brick may be found in SCPI Technical Notes 18, 18A, 18B.

b. Location. For data on location of expansion joints for brick and tile construction, see *Brick and Tile Engineering,* SCPI. (See Criteria Sources.) For data on expansion joints for concrete masonry construction, see Chapter 3. Also see *Crack Control in Concrete Masonry Unit Construction,* Federal Construction Council Technical Report No. 48. (See Criteria Sources).

2. CONTRACTION AND CONTROL JOINTS.

a. Shrinkage. Shrinkage classification of concrete masonry units is contained in Table 6-2.

b. Location. Locate control joints as follows:

(1) At wall intersections in L-, T-, or U-shaped buildings where expansion joints are not used.

(2) At or near cross wall intersections where the intersecting walls are 12 feet or more in length.

(3) Where joint reinforcement is not used, at intervals not exceeding 15 feet in walls of group 1 units, and 30 feet in walls of group 2 units.

TABLE 6-1
Thermal Movement

Material	Average coefficient of linear thermal expansion, in millionths (0.000001) per °F	Thermal expansion, in. per 100 ft for 100° F temp. increase (to closest 1/16 in.)
Clay masonry:		
Clay or shale brick	3.6	0.43 (7/16)
Fire clay brick or tile	2.5	0.30 (5/16)
Clay or shale tile	3.3	0.40 (3/8)
Concrete masonry:		
Dense aggregate	5.2	0.62 (5/8)
Cinder aggregate	3.1	0.37 (3/8)
Expanded-shale aggregate	4.3	0.52 (1/2)
Expanded-slag aggregate	4.6	0.55 (9/16)
Pumice or cinder aggregate	4.1	0.49 (1/2)
Stone:		
Granite	4.7	0.56 (9/16)
Limestone	4.4	0.53 (1/2)
Marble	7.3	0.88 (7/8)

TABLE 6-2
Drying Shrinkage Classification of Concrete Masonry Units

Kind of masonry unit	Weight of masonry unit per cu ft of concrete (lb)	Linear shrinkage[1] (percent)	
		Group 1	Group 2
Concrete brick.	100 or more	no limit	0.03 or less.
Hollow or solid concrete block.	105 or more	no limit	0.04 or less.
Hollow or solid concrete block.	less than 105	no limit	0.05 or less.

[1]Drying shrinkage tests are described in progress reports of ACI Committee 716, reprint title 49-53, published in the ACI.

(4) Control joints should not pass through bond beams, lintels, sills, special joint reinforcing at openings, or elsewhere if structural stability of the wall will be impaired.

c. Details. Typical control joints are shown in Figure 6-1.

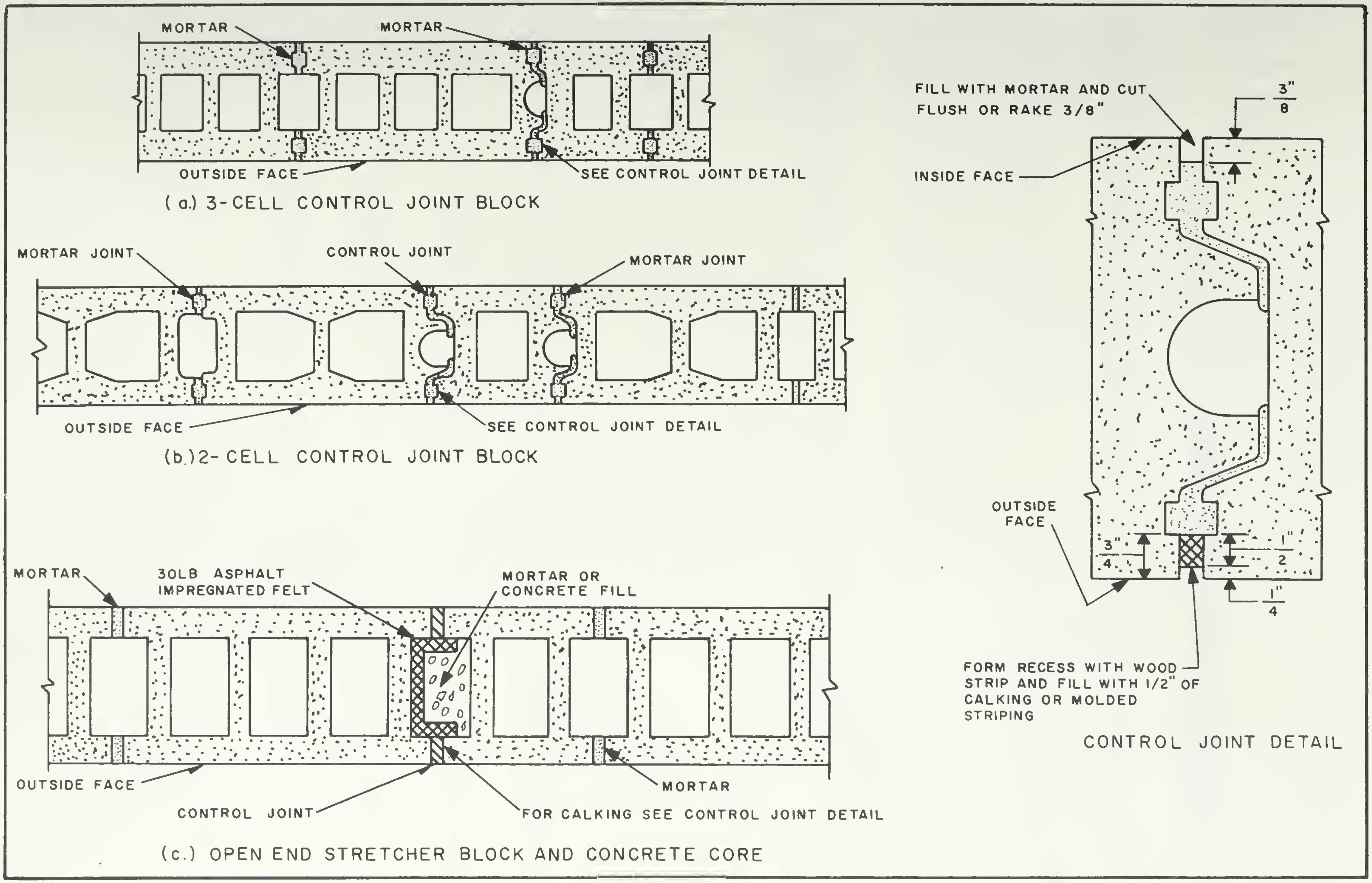


FIGURE 6-1
Control Joints

CHAPTER 7. COMPOSITE STRUCTURES

Section 1. SCOPE AND RELATED CRITERIA

1. **SCOPE.** Applications of steel, concrete, timber, and other materials to form composite arrangements utilizing the best features of each material in advantageous combinations are explained in this chapter. Composite structures are divided into three major classifications: steel-concrete, timber-concrete, and other types.

2. **RELATED CRITERIA.** For allowable stresses of materials, see the following chapters in this design manual:

Material	*Chapter*
Structural steel	2
Concrete	3
Timber	4

Allowable stresses in other materials are contained in manufacturer or trade association standards.

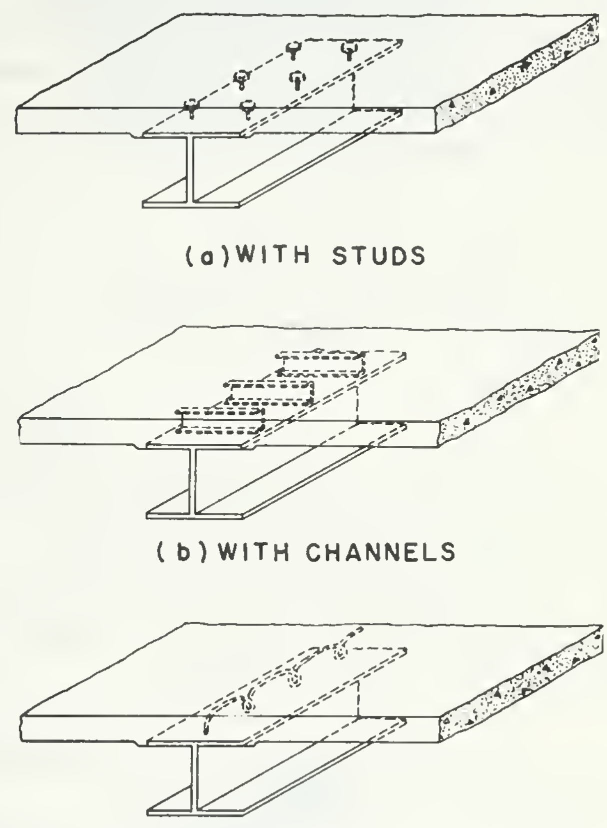


FIGURE 7-1
Composite Steel-Concrete Construction

Section 2. STANDARDS FOR DESIGN

Part 1. STEEL-CONCRETE COMPOSITE STRUCTURES

1. **TYPES OF SHEAR CONNECTORS.** Examples of composite steel-concrete construction are shown in Figure 7-1.

2. **STANDARD SPECIFICATIONS.** Requirements for structures of service classification A or B, relating to general requirements, shear connectors, effective flange width, horizontal shear, and deflection, shall be in accordance with the *Standard Specifications for Highway Bridges,* American Association of State Highway Officials (AASHO) (see Criteria Sources) with the following exceptions.

a. **Shear Connectors.** Shear connectors for class B structures need not be utilized for stresses below 0.025 f'_c, if the contact surface is adequately cleaned and not painted. Provide mechanical shear connectors if horizontal shear stress exceeds 0.025 f'_c and proportion for the entire shear stress.

b. **Creep.** For short term loadings (as moving loads), n shall be determined in accordance with the provisions of the AASHO Specifications. For long term loading (as dead load acting on the composite section or warehouse live load), n shall be assumed to be three times the value for short term loading.

c. **Shoring.** Where structures are shored under dead load, the dead load shall be considered taken

by composite action, provided a minimum of three shores (at quarter points) is provided.

d. Shrinkage. Steel stresses due to concrete shrinkage are seldom important, but may be checked on the basis of one of the following assumptions, either of which may be used for purposes of computation.

(1) Shrinkage does not cause cracking. In this case, the slab is in tension and the steel stresses may be evaluated by considering the composite cross section as an eccentrically loaded column, with a load of $0.0002E_c nA_c$ applied at the centroid of the slab, where:

A_c = area of concrete flange.

E_c = modulus of elasticity of concrete.

E_s = modulus of elasticity of steel.

$$n = \frac{E_s}{E_c}.$$

(2) Shrinkage causes cracking of the slab. The total opening of shrinkage cracks is equal to the unit shrinkage multiplied by the length of the beam. To close the cracks, the stress in the top flange of the steel beam must equal the noncomposite dead load stress plus $0.0002E_s$.

e. Expansion. The effects of expansion and differential temperature may be neglected.

f. Continuous Spans. The provisions for continuous spans are contained in Section 1.9.4 of the AASHO Standards. Distribution of the moments in the continuous composite members may be based on distribution factors for noncomposite sections, without appreciable error.

Part 2. TIMBER-CONCRETE COMPOSITE STRUCTURES

1. TYPICAL DETAILS. Typical details of timber-concrete composite structures are shown in Figure 7-2.

2. STANDARD SPECIFICATION. Requirements for structures of Service Classification A or B, relating to general requirements, shear connectors, effective flange width, horizontal shear, and deflection, shall be in accordance with the *Standard Specifications for Highway Bridges*, AASHO (see Criteria Sources) except as follows.

a. Shear Connectors. Standard plate shear connectors 3-3/4 by 3-1/2 by 3/32 inches shall have a shear capacity of 1,750 pounds each.

b. Shear Castellations for Composite Slab Construction. Shear castellations for composite slab construction is achieved by dapping 50 percent of the top edges to a depth of 1/2 inch. Ends of daps shall be sloped at 30 degrees from the vertical to reduce stress concentrations.

c. Joints in Timber Laminations. Laminations in composite slab decks shall be spliced one-third at each quarter-span point, and one-third over the interior supports.

d. Spikes to Resist Separation Forces. These spikes shall be 60d, at 2- to 4-foot centers, protruding a minimum of 1-1/4 inches and angled away from the center of span. Vertical spiral dowels or longitudinal bending grooves may be substituted for spikes.

e. Effective Flange Width. Flange width for stringer-slab construction shall be the least of the following:

(1) Sixteen times the thickness of the slab.

(2) One-fourth the span of the beam.

(3) The distance, center-to-center, of beams.

(4) Four times the width of stem.

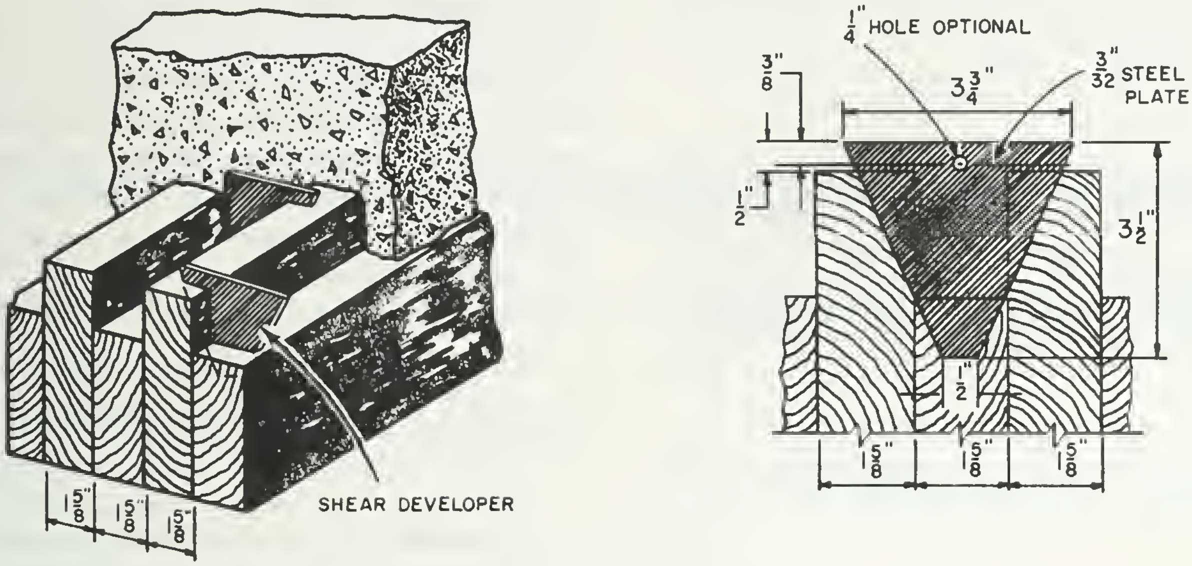
f. Slab Stringer Spans. Where large stringer spans are required, blue laminated or mechanically laminated members are preferable to solid sections.

g. Differential Temperature Stresses. Differential temperature stresses are not important, except with regard to shear stresses in connectors. The additional connectors required shall be computed from:

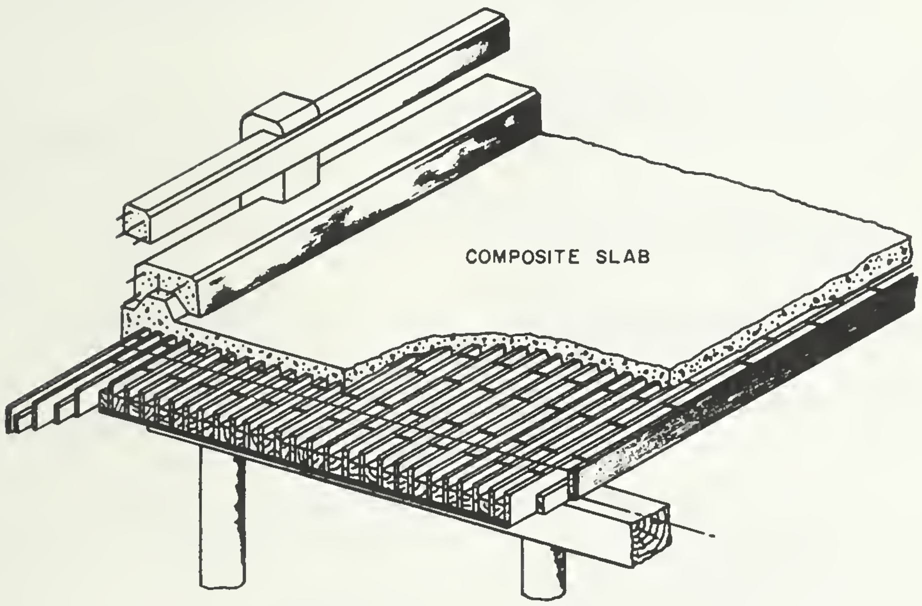
$$N = \frac{A_c f_c}{S}, \qquad (7\text{-}1)$$

where:

N = number of connectors required for temperature stress (uniformly distributed along beam).



STANDARD SHEET STEEL



DECK ASSEMBLY

FIGURE 7-2
Composite Timber-Concrete Deck

A_c = area of concrete flange.

f_c = concrete stress induced by differential temperature change.

S = value of each connector.

h. Other Exceptions. The provisions of Part 1 of this chapter relating to creep, shortening, expansion, and continuity shall apply. When computing shrinkage stresses, the n and k values for timber-concrete given in AASHO Specifications shall be used.

Part 3. SANDWICH PANELS

1. FACINGS. Use facings of plywood, aluminum alloy, galvanized or stainless steel, fiberglass, asbestos-cement board, or pressed board. Plywood and pressed board shall not be used for the interior facing of panels unless given a fire-retardative treatment.

2. CORES. Use cores of natural wood such as balsa, expanded fibers, cellular plastics, rubber, mechanically constructed cells of either grid or honeycomb construction, expanded glass, or asbestos. Where cellular plastics are used, the selection of the specific material shall be made in consultation with the NAVFAC Field Engineering Division's Fire Protection Engineer, to assure use of a firesafe material.

3. ADHESIVES. Use adhesives to bond facing cores that will provide a bond strength at joints in excess of the strength of the cores.

4. STRENGTH. In flexure, design the core to resist the shear, and the facing to resist the bending moments. Axial compressive loads are limited by buckling, dimpling, or wrinkling of the facing.

5. ADDITIONAL INFORMATION. See *Structural Plastics*, Chapter 6 (Bibliography).

CHAPTER 8. OTHER STRUCTURAL MATERIALS

Section 1. SCOPE AND RELATED CRITERIA

1. **SCOPE.** This chapter contains design criteria for structural applications of plastics, magnesiums, glues, gypsum, copper base alloys, and resins. Although structural applications of these materials have been generally limited, their characteristics are given together with available performance and pertinent criteria.

2. **RELATED CRITERIA.** Certain criteria related to the subject matter of this chapter appear in other chapters in this design manual:

Subject	*Chapter*
Factors of safety – aluminum	5
Timber construction	4

Section 2. PLASTICS

1. **APPLICATIONS.** Structural applications of plastic include precast panels for walls and roofs, shell-type roof coverings, tanks, boats, sandwich panels, and membranes for air supported structures.

2. **MATERIALS.** Many usable plastic materials are available. Some are proprietary, and some for structural applications have not been standardized.

a. **Reinforced Plastics.** Reinforced plastics are composed primarily of plastic resin and reinforcing material. The reinforcement is usually fiberglass, and is intended to improve the properties of the plastic. Since many different materials are available, the properties can usually be tailored to specific requirements.

3. **PROPERTIES.** Refer to *Modern Plastics Encyclopedia* (see Bibliography). Specific information should be obtained from the manufacturer.

4. **DETAIL DESIGN CONSIDERATIONS.** The following characteristics and properties apply.

a. **Creep.** A low modulus of elasticity and a tendency to creep are characteristic of plastics that result in large deflections and permanent deformations.

b. **Allowable Stress.** The maximum stress depends on the material and the application, usually limited to 1/3 or 1/4 of ultimate strength.

c. **Fatigue.** Where fatigue is a consideration, consult the manufacturer.

d. **Thermal Expansion.** Plastics have relatively high rates of thermal expansion. Check temperature stresses when bonded to other materials.

e. **Environmental effects.** Check properties at high and low temperatures.

5. **OTHER PROPERTIES FOR STRUCTURAL USAGE.** Where contact with specific chemicals is expected, the resistance of the plastic should be checked.

a. **Fire Resistance.** Most plastics either burn or are self-extinguishing. Additives can be included in some plastic compositions to retard burning or make them self-extinguishing. For noncombustible application, only those plastics listed by Underwriters Laboratories, Inc., as having a flame spread of 25 or less should be considered for use. Smoke development should be 50 or less where it is a factor.

Section 3. MAGNESIUM

1. **APPLICATIONS.** Structural applications of magnesium include aircraft, materials handling equipment, vehicles, and other area where low weight is important.

2. **MATERIALS.** Many magnesium alloys and tempers are available. Alloys and tempers suitable for structural applications have not been completely standardized and must be chosen by the designer for the job.

3. **STRUCTURAL PROPERTIES AND WORKING STRESSES.** Typical structural properties of magnesium alloys and tempers are given in *Magnesium Design*, Dow Chemical Corp. (See Criteria Sources.) Properties indicated in this publication are typical.

a. **Strength Properties.** Strength properties for magnesium should be specified as minimum values and suppliers should be required to guarantee them.

b. **Working Stresses.** Working stresses of magnesium shall be based on percentages of yield strengths. Use safety factors similar to aluminum construction. (See Chapter 5.)

c. **Combustibility.** Magnesium is combustible, and when ignited is extremely difficult to extinguish. Accordingly, it must be used with proper consideration of the hazard.

4. **DETAIL DESIGN CONSIDERATIONS.** Detail design considerations shall be similar to those for aluminum design described in Chapter 5. Specific properties with respect to temperature effects, fatigue strengths, and buckling characteristics are included in *Magnesium Design*, Dow Chemical Corp. (See Criteria Sources.) Consider the low modulus of elasticity and high coefficient of thermal expansion.

5. **CORROSION TREATMENT.** Chemically treat, paint, or otherwise properly protect all magnesium surfaces. Do not use magnesium in locations subject to electrochemical action unless completely isolated.

Section 4. GYPSUM

1. **APPLICATIONS.** Gypsum has many structural applications as a substitute for concrete where dry conditions prevail. The principal application is for roof decks. Gypsum also has been used in floor construction; the material softens when wet.

2. **ALLOWABLE LOADS AND SPANS.** Allowable loads and spans for gypsum roof decks (precast and poured-in-place) have been developed by gypsum suppliers. They are tabulated in standard catalogs and should be referred to for design standards.

3. **DESIGN DETAILS.** Design standards for gypsum are contained in many suppliers and manufacturers catalogs.

Section 5. COPPER BASE ALLOYS

1. **APPLICATIONS.** Structural applications of copper and copper base alloys usually are limited to applications where corrosion resistance or low-friction values are required.

2. **MATERIALS.** Many copper base alloys and tempers are available. Except for use in bridge bearings and expansion plates, suitable alloys and tempers for structural usage are not standardized completely and must be chosen by the designer.

3. **STRUCTURAL PROPERTIES.**

a. **Strength.** Minimum strength properties for various copper base alloys are given in American Society for Testing and Materials (ASTM) Specifications.

b. **Modulus of Elasticity.** The copper modulus is about 17,000,000 psi. The addition of zinc to copper (yellow brass) reduces the modulus to about 15,000,000 psi. Bronzes have values from about 15,000,000 to 17,000,000 psi. The addition of nickel to copper increases the modulus; Cupronickel 30 percent – 702 has a modulus about 22,000,000 psi.

c. **Fatigue Strength.** For collateral reading, see *Proceedings*, Vols. 35, 37, 41, 43, and 46, ASTM and *The Metals Handbook*, ASM. (See Criteria Sources.)

4. **ALLOWABLE STRESSES.** Allowable stresses of copper base alloys should be one-third to one-quarter ultimate strength values.

Section 6. GLUE-TYPE FASTENERS

Part 1. EPOXYS

1. APPLICATIONS. Structural applications of epoxy glues are for repairs and alterations primarily, particularly the bonding of masonry or metal to concrete. Metal-to-metal applications also have been used in airframe construction.

2. STRUCTURAL PROPERTIES. There are many epoxy compounds with varying properties. For information on selecting the proper adhesive, see *Military Standardization Handbook*, MIL-HDBK 691. In order to assure the maximum properties of the adhesive are obtained, the manufacturer's instructions on preparation, mixing, application, and hardening should be carefully followed.

a. Strength. The values below can be realized only by carefully following recommended installation procedures.

(1) Shear: 2,000 psi.
(2) Compression: 5,000 psi.
(3) Tension: 3,000 psi.

b. Temperature Effects.

(1) Application temperature for epoxy is 60° to 90° F.

(2) High temperature or prolonged exposure to temperatures over 225° F will destroy epoxy compounds.

(3) Coefficient of thermal expansion is about three times that for steel or concrete.

c. Creep. No reliable creep data are available.

d. Fatigue. Fatigue has no significant effect on epoxy compound properties.

e. Impact Resistance. The impact resistance of epoxy compounds is excellent.

f. Other Properties. Epoxy compounds will burn, but are self-extinguishing.

Part 2. WOOD GLUES

1. TYPES. The principal wood glue types are animal, casein, and resin.

2. STRUCTURAL PROPERTIES. Specific structural properties of wood glues need not be considered. Use the design criteria for timber construction in Chapter 4 to insure adequacy of joints made with approved wood glues. For further information on wood gluing, see *Handbook on Adhesives*, Chapter 43 (see Bibliography).

CHAPTER 9. STRUCTURAL SYSTEMS

Section 1. SCOPE AND RELATED CRITERIA

1. **SCOPE.** Criteria and data resulting from experience which will assist the designer in the selection of economical structural systems for steel, reinforced concrete, and timber structures are found in this chapter.

2. **RELATED CRITERIA.** Certain criteria related to structural systems appear in other chapters of this design manual and in other manuals in the design manual series, as cited:

Subject	*Source*
Allowable loads	Chapter 1
Butts and range structures	NAVFAC DM-27
Fireproofing	NAVDOCKS DM-8
Foundation requirements	NAVFAC DM-7
Impact allowance	Chapter 1
Missile launching facilities	NAVFAC DM-31
Modular design	NAVDOCKS DM-1
Retaining wall loads	NAVFAC DM-7
Sheet pile and steel pile structures	NAVFAC DM-7
Steel storage tanks	NAVFAC DM-22
Surface and aboveground tanks–reference standards	Chapter 2
Vibration isolation	NAVFAC DM-3

3. **OVERALL CONSIDERATIONS.** The best structural system for a given application is that which will satisfy the functional and architectural requirements of the finished structure at minimum cost. Consideration should be given to future uses of the structure, possibility of alterations, and maintenance costs. Also consider ease of demolition of temporary structures or dismantling of portable structures. Preferred systems utilize material efficiently, provide maximum usable space, minimize the use of special equipment, and can be constructed by following conventional procedures.

4. **POLICY.** Although the Navy is not obligated to conform to local building codes, it is the policy of the Naval Facilities Engineering Command to avoid infringement of the regulations and standards of such codes.

Section 2. PRELIMINARY CONSIDERATIONS

1. **MATERIAL SELECTION FACTORS.** Material selection factors are listed in Table 9-1.

2. **MODULAR DESIGN.** Coordinate modular design features with architectural requirements favoring repetition of units. Beam depths and spacing, column spacing, floor heights, locations of openings, and clearance are typical considerations. See *Architecture*, NAVDOCKS DM-1, for additional discussion on modular design.

3. **WALL BEARING VERSUS FRAMED STRUCTURES.** Before selecting the type of framing system, determine if the structure is to be wall bearing or framed. Weigh the following factors:

Factor	*Comment*
Height of structure	Wall bearing construction usually is limited to one- or two-story structures.
Wall openings	Framed structures are desirable where building walls are pierced by many openings.
Shock and seismic loads	Wall bearing structures are desirable for shock (blast and seismic) loads, if intersecting cross walls are provided and if walls, floors, and roofs are rigidly connected. If the above provisions cannot be met, framed structures are preferable.

TABLE 9-1

Material Selection Factors

Factor	General requirements	Detailed considerations
Availability	Use materials, sizes, or shapes readily available.	1. Use supplies locally available. 2. Concrete is available in cold weather, only with special precautions. 3. Avoid use of special rolled steel shapes, which usually cost extra.
Speed of erection	In general, savings in time will reflect savings in cost.	1. Consider precast units for repetitive work in lieu of cast-in-place concrete. 2. Concrete systems with precast slabs and cast-in-place toppings can be used to eliminate forms. Such construction can act integrally for live load if suitable shear connectors are used at interface of precast and cast-in-place portions. 3. Permanent corrugated metal forms can be used in lieu of conventional formwork. 4. Where practical use welded wire fabric rather than bar reinforcements. 5. High early-strength concrete may be used to facilitate rapid form removal.
Weight	Cut weight for subsequent savings throughout structure.	1. Where foundation problems exist, avoid concrete construction in the superstructures or substitute lightweight concrete. 2. For precast components shipped long distance, use lightweight concrete. 3. Consider high strength concrete to reduce sizes of floor members and columns. 4. Consider one way and two way concrete rib slabs. 5. Consider high strength steels for long span structures.
Strength	Materials must be adequate for structural and erection load stresses.	1. Consider erection stresses for all precast members. 2. Use added reinforcements for symmetrical placement in precast elements. This prevents breakage from improper positioning. Positioning of precast element in work shall be clearly marked on the piece.
Stiffness	Increase stiffness to limit deflections.	1. Consider rib slabs for increased stiffness with little weight increase. 2. Consider composite construction. 3. Consider increasing depth of steel joists over minimum requirements for increased stiffness with little added weight. 4. Consider laminated timber beams for increased sizes in lieu of solid members.
Fireproofing	Select materials in consonance with the fire rating requirements of the structure. (This is frequently the controlling consideration in the selection of materials.)	1. See NAVDOCKS DM-8 for criteria. 2. Concrete construction is inherently fireproof and requires no further treatment. 3. To reduce weight, consider vermiculite protection rather than concrete encasement for steel framing.
Moisture protection	Limit moisture penetration into structure and prevent moisture (or condensate) from coming in contact with bare steel or timber.	1. Use dense concrete mixes. 2. Provide waterstops at all joints in concrete walls and slabs below grade. 3. Provide membrane or hydrolithic waterproofing for occupied spaces below grade. 4. Use preservative-treated timbers, as indicated in Chapter 4. 5. See NAVDOCKS DM-1.
Durability	Choose materials to assure economic life of the project.	1. Consider air entrained concrete for structures exposed to extreme weather conditions. 2. Consider corrosion resistant steels (particularly copper-bearing or some alloy steels) where maintenance is difficult.

TABLE 9-1 (Continued)
Material Selection Factors

Factor	General requirements	Detailed considerations
		3. Consider use of protective coatings or treatments in lieu of more expensive materials. (a) Preservative-treated timbers. (b) Galvanizing (See NAVDOCKS DM-25). (c) Concrete jackets. 4. See Chapter 4 for timbers resistent to decay and borer attack. 5. See Chapter 2 for corrosion rates of various steels.
Local labor and construction practice	Use materials and construction methods familiar to local labor.	1. Avoid complicated systems or fabrication requiring unduly accurate positionings, alinements, or adjustments unless skilled labor is available. 2. Consider use of prefabricated assemblies that can be erected by semiskilled labor.

Factor	*Comment*
Slanting construction. .	Wall bearing structures, subject to above limitations, are inherently shock-resistant and are suitable for slanting construction.
Structural materials . .	Structures utilizing masonry walls and timber framing are more readily adaptable for wall bearing construction than reinforced concrete or steel framed structures.

Section 3. STEEL STRUCTURAL SYSTEMS

1. FLOOR FRAMING SYSTEMS. Floor framing systems data contained in Table 9-2 relating to types of construction, suitable spans, loads, and other factors may be used as a guide in selecting a suitable floor framing system for a steel building.

2. ROOF FRAMING SYSTEMS. The framing data indicated in Table 9-2 are equally valid for the selection of roof systems, subject to the following considerations.

a. Loads. Roof loads usually are lighter than conventional floor loads.

b. Spans. Roof deck spans and lengths of supporting members may be increased because of decreased loads.

c. Deflections. Criteria for deflection limitations are less severe.

d. Pitch. Roofs for all new structures shall have a slope of not less than 1/2 inch per lineal foot. Exceptions to this are slopes for large areas, such as warehouses, which may be 1/4 inch per foot minimum, provided the roof deck is stiff enough to prevent ponding; also when extensions are made to existing buildings, the roof slopes may match the existing roofs. Where the slope of a built-up roof is less than 1/2 inch per lineal foot, the roof shall be coated with coal tar pitch or low slope asphalt.

e. Surface Treatment. Provide roofing and waterproofing materials. However, industrial sheet metal roofing may be exposed and concrete roof slabs may be left exposed if:

(1) The location is such that there is little temperature variation and only moderate rainfall.

(2) Concrete strength is a minimum of 3,000 psi.

(3) Concrete is carefully controlled in the mixing and placing, troweled to a smooth finish, and properly cured.

(4) The design of structures is adequate to prevent settlement of the foundation or excessive cracking of roof slab.

(5) The smallest practicable size steel reinforcement and the smallest aggregate are used.

(6) The use of white cement is considered in lieu of gray for better reflectivity.

3. PITCHED ROOFS. Pitch roofs in excess of drainage requirements to suit necessary interior clearances for structural efficiency by using deeper trusses to aid in natural illumination or ventilation. Roofs pitched in excess of 3:12 may be designed for lighter snow load (in areas where snow loads are applicable) than flatter roofs.

TABLE 9-2
Selection Factors for Steel Floor Framing Systems

Type	Applications	Live loads[1]	Spans[1]	Requirements
Beam and girder beam and truss.	1. Use in conjunction with concrete, steel deck, precast plank, and almost all slab systems. 2. Adaptable to future changes, reinforcements, and alterations. 3. Openings for stairs, elevators, etc., easily framed. 4. Local load concentrations from equipment readily accommodated. 5. Adaptable for irregular column spacings.	Unlimited.	Generally 20 to 30 ft between trusses, with truss spans unlimited.	1. For economy, beams generally should span short directions and girders long directions. 2. Economical multistory construction; for bays of 20 to 26 foot spans. 3. Space beams to suit slab or deck limitations.
Open-web steel joists.	1. Rapid erection. 2. Suited to framed or wall bearing structures. 3. Connections to support members may be welded or field bolted. 4. Open webs allow passage of pipes, ducts, and conduits within floor depth. 5. Can be used with timber, precast or cast in place concrete, or metal decks. 6. Generally require hung ceiling for fireproofing. 7. Adaptable for irregular column spacings. 8. Not suitable for support of heavy concentrated loads (or heavy loads, in general).	Light to medium.	Short span series, 12-48 ft. Long span series, up to 96 ft.	1. For load capacities, bridging, etc., see *Standard Specification and Load Tables,* Steel Joist Institute (SJI). 2. Maximum spacings of joists are usually:[1] (a) 24 inches for floors. (b) 48 to 60 inches for roofs (concrete slabs). (c) 7 feet for roofs (steel deck or timber deck). 3. Provide double joists under partitions, or other load concentration lines. 4. Provide extra stiff joist framing on column lines for bracings. 5. Do not use in exposed locations.
Junior beams light beams.	1. Very light construction.	Light.		1. Avoid in corrosive environments. 2. Use only for light framing (roof or stair construction).
Battledeck floor.	1. Incorporates series of rolled steel beams with welded steel top floor plates acting as composite sections. 2. Relatively expensive.	Heavy.	Unlimited.	1. Use for heavy floor loads.
Cellular floor.	1. Available in many shapes, depths, thicknesses, with or without top and/or bottom plates. 2. Light weight framing system. 3. Cells form conduits for electrical, telephone, and other wiring. 4. Requires cuttings around columns and members piercing floor.	Light to medium.	Floors 8 to 10 ft with some sections capable of 18 to 20 ft spans. Roof up to 25 ft.	1. Provide concrete toppings for floor use. 2. Provide concrete or gypsum toppings for roof use. 3. Weld deck to each supporting beam. 4. Provide special framing at columns where wind moment connections interfere with decks. 5. See manufacturers' catalogs for load capacities.

[1] Loads, spans, and spacings indicated represent an economical range of values for the particular type of framing under normal design conditions. Within limits, where functional or architectural requirements dictate, these systems can be adapted for loads and spans outside of ranges indicated, but usually, at a sacrifice in economy.

TABLE 9-2 (Continued)
Selection Factors for Steel Floor Framing Systems

Type	Applications	Live loads[1]	Spans[1]	Requirements
Short-span concrete deck (on steel framing).	1. Formwork for slabs hung from steel beams to eliminate shores. 2. Rapid placement of reinforcings with welded wire fabric. 3. Alterations easily made. 4. Erection of steel framing unlimited by progress of slab pouring operations. 5. Utilizes low grade concrete for slabs.	Light to medium.	15 to 25 ft (spacing of joists 6 to 12 ft).	1. Use draped welded wire fabric in lieu of reinforcing bars. 2. Set tops of steel beams 1½ inches below tops of slabs or, 3. Use high chairs to support wire fabric when tops of beams are near bottoms of slabs. 4. Reduce end spans to utilize one size of wire fabric on project or, 5. Provide extra layer of wire fabric in end spans. 6. Consider addition of 4 inch fill and finish over structural slabs.
Suspended span (cantilevers with suspended section).	1. Roof construction. 2. Weight of steel per square foot of roof is very light.	Light to medium.	Generally long spans, but may be used for purlins.	

[1] Loads, spans, and spacings indicated represent an economical range of values for the particular type of framing under normal design conditions. Within limits, where functional or architectural requirements dictate, these systems can be adapted for loads and spans outside of ranges indicated, but, usually, at a sacrifice in economy.

4. **ROOF TRUSSES.** Select from Table 9-3 specific roof truss types for economical, functional, and architectural reasons. Locate all trusses at spacings (spans) indicated in Table 9-2 as economical for subframing. See Figures 9-1 and 9-2 for types of roof trusses.

5. **BRACING REQUIREMENTS.** Unless otherwise specified for particular structures, bracing requirements shall be as follows.

a. **Lateral Bracing.** Strength required in lateral bracing to prevent buckling of a compression member (or flange) generally is less than 5 percent of the strength of the compression member (or flange) acting as a column between brace points. Where brace members (including purlins and joists) and their connections are proportioned to provide such strength at normal working stresses, they may be considered as providing lateral support for compression members or flanges. For collateral reading, see *Lateral Bracing of Columns and Beams*, ASCE. (See Criteria Sources.)

b. **Minimum Strength.** Provide at least two bolts to a connection or a minimum load of 6,000 pounds per connection.

c. **Knee Braces.** Use knee braces at connections between trusses (or open-web joists) and columns unless grip of truss end on column provides adequate stiffness.

(1) Knee-braced connections, unless specifically so designed, shall not be considered as effecting any reduction in span of intersecting beams, girders, or trusses.

(2) Consideration shall be given to the thrust exerted on the column through the knee brace as a result of deflection of the truss or girder. Consider tightening (or welding) the knee brace connection after full dead load is on the structure.

d. **Diagonal Braces.** Provide diagonal braces in top and bottom chord planes of roof trusses.

(1) For end bays and bays with crane runways, use stiff sections for bracing. Threaded tie rods may be used for all other bracing.

TABLE 9-3
Roof Truss Data

Types of trusses	Suitable span[1] (feet)	Typical applications	Remarks
Simple Fink, Fan Fink, king post, queen post	30 to 40	Small shops where pitched roofs are required	King post and queen post more popular in wood construction.
Compound Fink, compound fan	50 to 80	Shops or mills where pitched roofs are required	. . . .
Pratt, Warren	50 to 100	All types of industrial buildings	. . . .
Camel back	50 to 120	Convention halls and train sheds	Appearance of trusses important.
Three-hinged arch	100 to 300	Aircraft hangars, armories, gymnasiums	. . . .
Scissors, hammer-beam	20 to 40	Churches, institutions	Usually wood construction.
Sawtooth	30 to 50	Industrial buildings	Uniform and efficient lighting.
Bowstring, crescent	40 to 80	Garages and small hangars	. . . .

[1] Spans indicated represent an economical range of values for the particular type of framing under the normal design conditions. Within limits, where functional or architectural requirements dictate, these trusses can be adapted for spans outside of ranges indicated, but, usually, at a sacrifice in economy.

(2) Provide bracing during erection to stiffen skeleton for all wall bearing structures.

e. Struts. Provide struts in top and bottom chord planes of roof trusses at ends of trusses and at intermediate points as required for L/r of truss chords. Provide web system for struts every third or fourth bay. The lines of bottom chord horizontal struts shall be continuous for the length of the building.

f. Sway Bracing. Provide vertical longitudinal sway bracing between roof trusses where required by lengths of span or other considerations. Sway braces should be located in two adjacent bays, rather than in separate bays at ends of building section, to minimize restraint against movement of structure under temperature change.

g. Column Bracing. Brace all columns in end walls.

6. RIGID FRAMES. Place rigid frames at the spacings (spans) indicated in Table 9-2 as economical for subframing. Rigid frame details are shown in Figure 9-3. The advantages and disadvantages of using rigid frames instead of simple framing are as follows.

a. Advantages. The advantages of using rigid frames are:

(1) They allow a more effective use of material (and decreased dead load), as compared to simple beam framing.

(2) They are shaped to suit structural or architectural requirements.

(3) They are easier to maintain, compared to trusses, because of fewer surfaces subject to corrosive effects.

(4) They provide added strength for slanting construction at low cost.

b. Disadvantages. The disadvantages of using rigid frames are:

(1) They have a higher unit cost of material and connections than simple framing.

(2) They may be less suitable for poor foundation conditions.

(3) They are more sensitive to temperature stresses than simple framing.

c. Members. Use three-plate welded member shapes. For sections of varying depth, diagonally cut, rolled shapes, turned end-for-end and welded can be used, as shown in Figure 9-3. Avoid splices near haunches or other areas of high stress.

d. Connections. Locate splices and connections in low stress areas. Consider bolted connections and splices to minimize field welding. If welded connections are used, they should be made with continuous, rather than intermittent, welds.

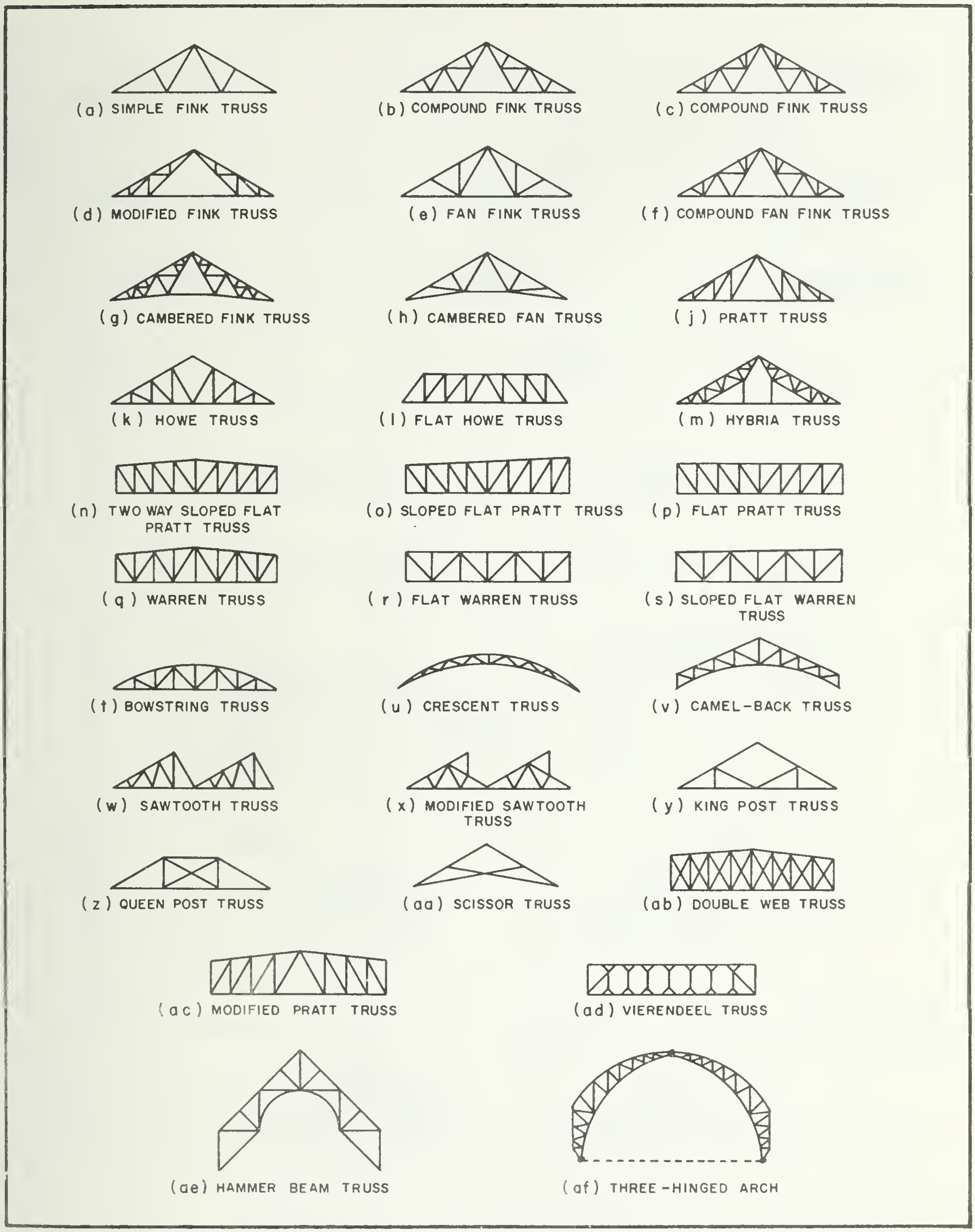


FIGURE 9-1
Types of Roof Trusses

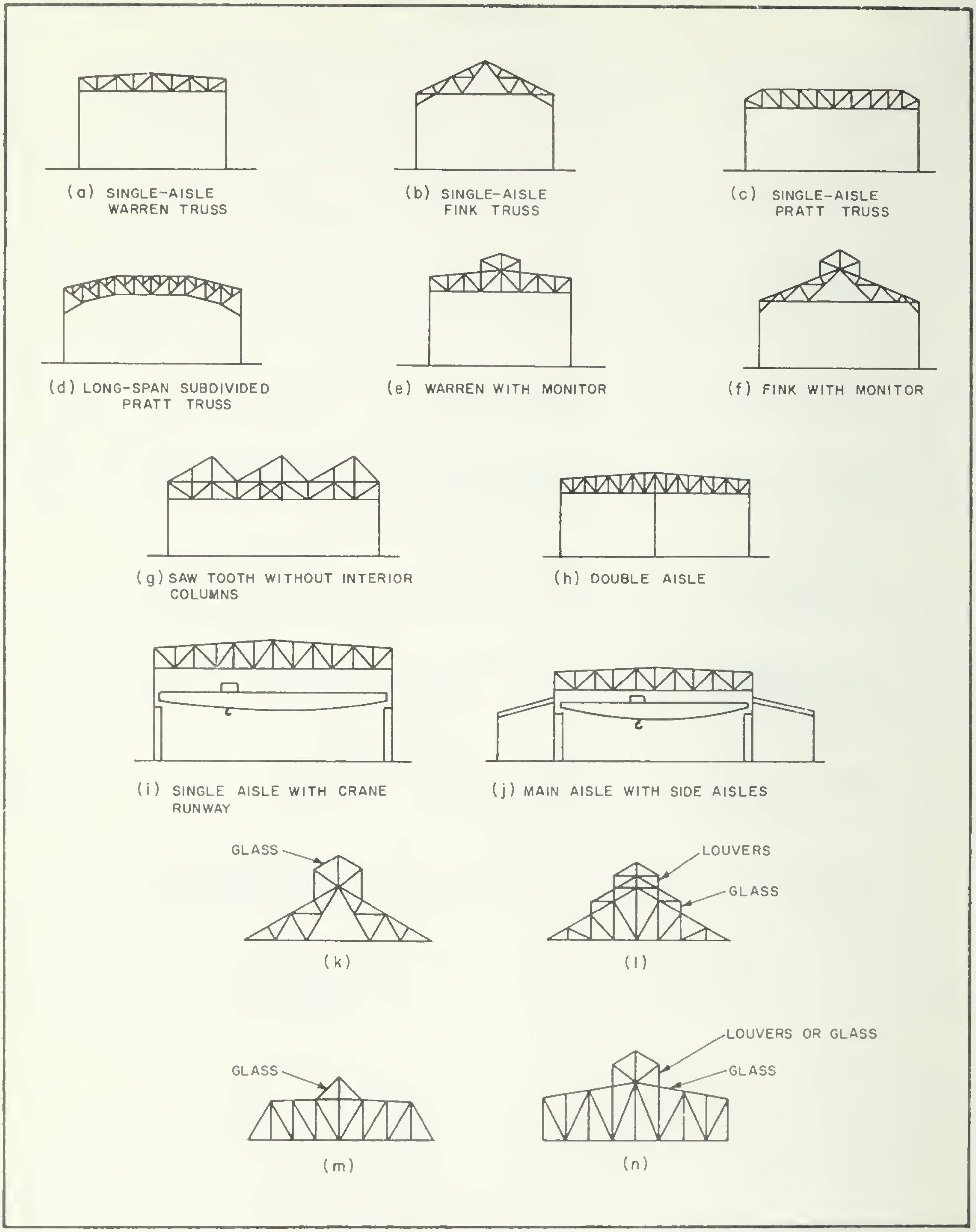


FIGURE 9-2
Roof Trusses With or Without Monitors

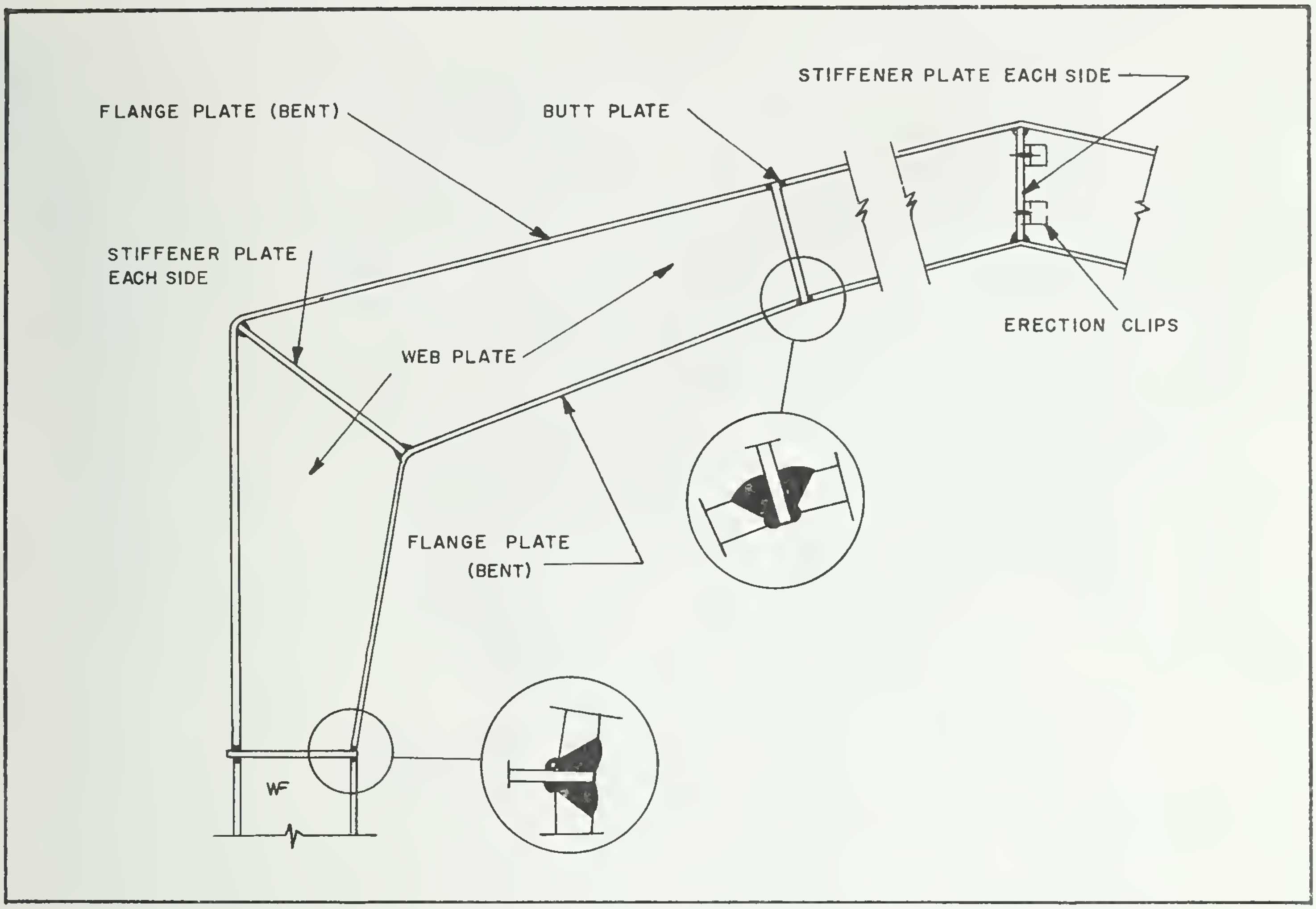


FIGURE 9-3
Details of Built-Up Knee and Butt-Plate Splices in Rigid Frame Bents

e. Bracing. The following items shall be provided:

(1) Provide diagonal bracing in top flange planes of bents. Bracing can be below levels of purlins to avoid interferences.

(2) Provide struts at haunches, with bracket connections, or braces, to stiffen compression flanges.

(3) Provide vertical column bracing between bents.

7. WEDGE BEAM FRAMES. Wedge beam frames utilize the concept of a simple cantilever beam (Figure 9-4). Space frames at spacings (spans) indicated in Table 9-2 as economical for subframing.

a. Advantages and Disadvantages. Wedge beam frames have advantages and disadvantages similar to those listed for rigid frames, with these added advantages:

(1) Expansion joints between frames are not necessary.

(2) Stresses due to temperature changes are very low.

(3) Wedge beams are adaptable for poor foundation conditions.

b. Members, Connections, Struts, and Bracing Requirements. Members, connections, struts, and bracing requirements are similar to those for rigid frames. (See Paragraph 6.)

8. ARCHES. In general, arches are economical only for spans exceeding 120 feet.

a. Types. The types of arches are listed below.

(1) *Fixed Arch.* The fixed arch is the most economical, where foundation or abutment conditions permit its use.

(2) *Arch Hinged at Abutments (Two-Hinge).*

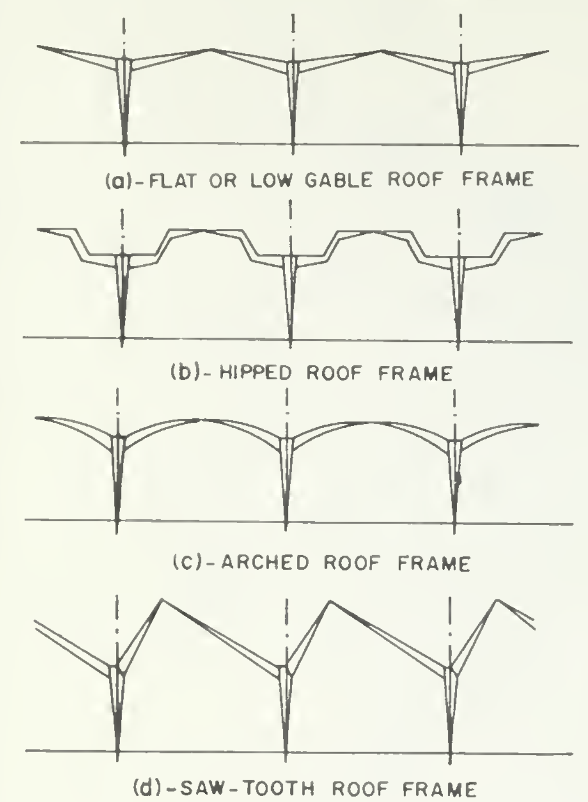


FIGURE 9-4
Typical Outlines of Wedge-Beam Framing

(3) Arch Hinged at Crown, Fixed at Abutments (One-Hinge). The hinged at crown arch is rarely used.

(4) Arch Hinged at Crown and Abutments (Three-Hinge). The arch hinged at crown and abutment structure is statically determinate, but is more flexible than the two-hinge or fixed type.

(5) Tied Arch. Where foundation or abutment conditions are such that they cannot support large horizontal thrusts, tied arches may be used. The stresses due to interaction between the tie and rib are appreciable, and shall be considered in designing this type of structure.

b. Framing Arrangements. Where the live-to-dead load ratio is small, the use of arch construction is advantageous in reducing differential thrusts of adjacent arches. Effects of partial live loading shall be considered. For main ribs, consider the use of open-web, all-welded types with segmental parallel chords. Tees for chords, and angles or Tees for web members are shown in Figure 9-5.

c. Bracing. Bracing requirements are the same as for trussed roof bracing, allowing for the fact that both top and bottom chords may be in compression.

9. MULTISTORY RIGID FRAMES.

Multistory rigid frames are preferable for tall, narrow structures and structures where diagonal column bracing, knee braces, or shear walls are undesirable because of weight, space, or architectural and functional considerations.

a. Advantages. The use of multistory rigid frames will result in story heights being reduced due to shallower beam depths, and the total weight of steel being less than for simple framing.

b. Disadvantages. The disadvantages of multistory rigid frames are:

(1) Steel unit cost is high.

(2) It is less rigid than braced structure or structure utilizing shear walls.

10. SUSPENDED ROOF CONSTRUCTION.

Suspended roof construction is limited to use in long span construction, such as in auditoriums, stadia, and hangars. It is sometimes combined with arch ribs in lieu of abutments to anchor cables.

a. Advantages. The advantages of suspended roof construction are:

(1) Very lightweight construction.

(2) Easy erection.

b. Disadvantages. The disadvantages of suspended roof construction are:

(1) It requires heavy anchorages, tension piles, or ring structure to take cable tensions.

(2) It is very flexible and sometimes subject to flutter in a heavy wind. Consider the possibility that wind suction may exceed dead weight of roof structure.

(3) It is more sensitive to distortion under temperature changes than more massive constructions.

c. Design Details. If suspended roof construction is considered preferable, the following design details shall be considered:

(1) The use of stay cables for stiffening.

(2) The use of prestretched rope, preferably with wire core, to minimize inelastic stretch.

(3) The use of [illegible] (perforated sheet metal tubes) for encasement of cables to minimize temperature changes.

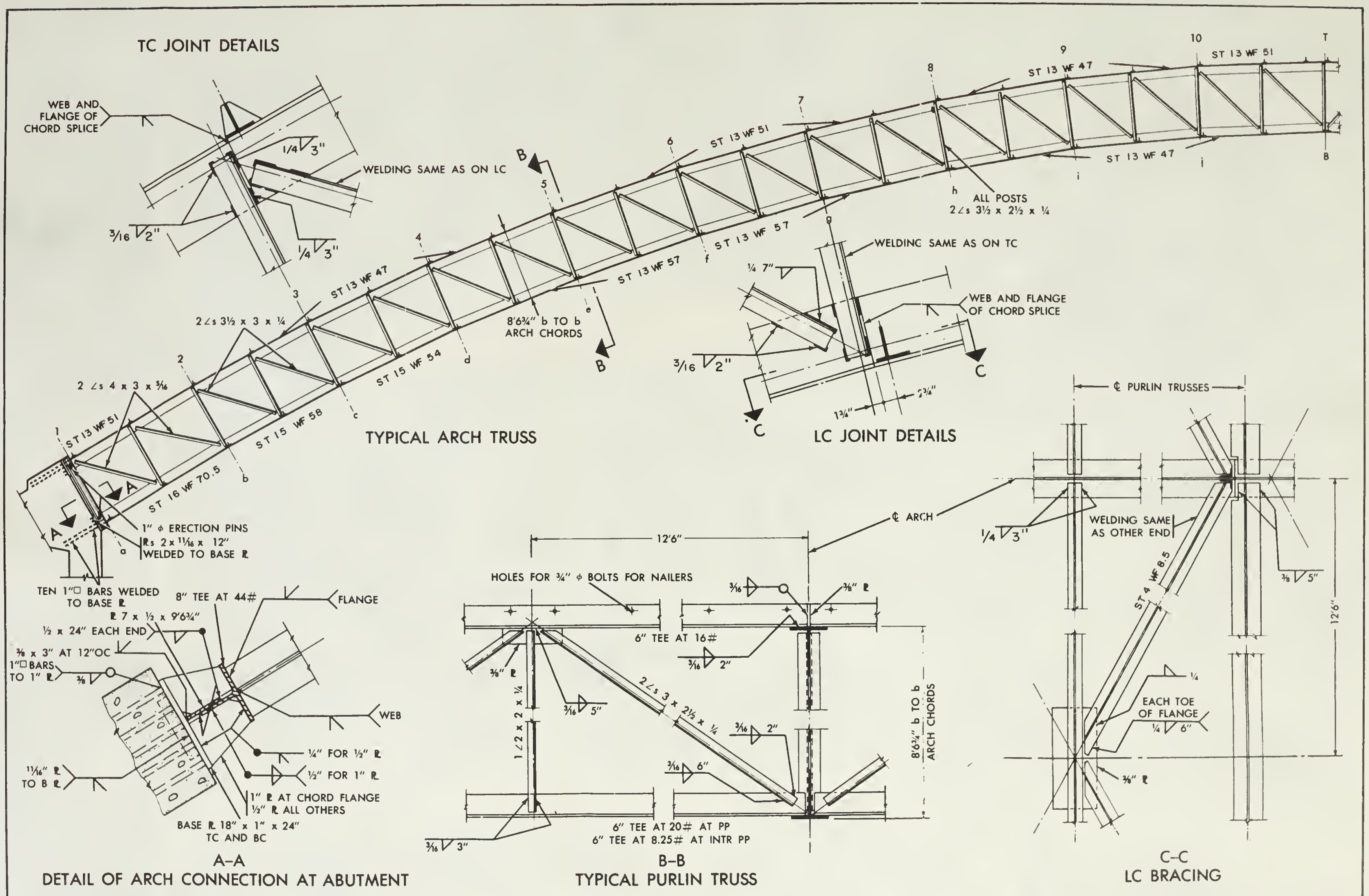


FIGURE 9-5
All-Welded Steel Arch for Long Span Construction

(4) The provision for takeup in end fittings.

(5) Partial live load conditions in design.

11. STEEL STORAGE TANKS. The overall requirements pertaining to the design of steel storage tanks are contained in Chapter 2 and in *Liquid Fueling and Dispensing Facilities*, NAVFAC DM-22.

a. Surface or Aboveground Tanks. The following criteria should be considered when designing surface or aboveground tanks:

(1) All-welded design is preferable to riveted design, except for temporary structures.

(2) Vertical storage tanks should be cylindrical.

(3) Vertical surface tanks shall be provided with a concrete ring wall extending from below frost line to level of sand pad. The ring wall may be omitted for small tanks (10,000 barrels, or equivalent capacity), for temporary structures, or where frost heave is not a problem.

(4) Shell design shall consider principal stresses due to combining ring stresses with vertical axial and bending stresses.

(5) When computing bending moments in the vertical plane, consider boundary conditions at top and base. See sources of standards noted in Chapter 2.

(6) Braced towers for elevated tanks are preferable to single column supports, except where the riser pipe is used as a vertical support. Braced towers shall have diagonal braces and struts in each tower support plane, and bottom struts, where used, shall connect to legs as close to the base as possible.

(7) Foundation requirements shall be in accordance with the recommendations in Appendix B of API-650. Also see *Soil Mechanics, Foundations, and Earth Structures*, NAVFAC DM-7, for additional criteria.

b. Underground Tanks. The criteria cited shall be followed when designing underground tanks.

(1) Earth Cover. Provide earth cover over top of tank in accordance with frost penetration requirements (considering concrete distribution slab), but not less than 3 feet.

(2) Foundation. Provide a reinforced concrete slab as a foundation for the tank. The steel bottom shall be anchored to the slab to prevent failure resulting from water pressure between slab and steel bottom (Figure 9-6). The space between slab and steel bottom shall be filled with a suitable bituminous calking material for a minimum distance of 1 inch in from the outer edge.

(3) Backfill Material. Backfill for all underground tanks shall include a 6-inch course of inert sand or fine gravel placed against all exposed exterior surfaces. A sheet of insulating fiberboard can be used in lieu of the sand or gravel.

(4) Bracing. Shell bracing, in the form of horizontal and vertical stiffeners, shall be provided. Horizontal stiffeners shall be structural T-sections fillet welded to shell plates. Weld ends of vertical stiffeners to horizontal stiffeners and to top and bottom plating. Shell and stiffeners shall be proportioned for loads as indicated in Chapter 2. Provide drain holes in horizontal stiffeners. Horizontal stiffeners shall be proportioned for ring buckling. Vertical stiffeners shall resist bending moments due to external loads considering vertical strips and ignoring shell action.

(5) Roof Construction. Roof construction should consist of a concrete, one-way slab spanning between roof support beams, with the structural action of the roof plating neglected. The lower layer of reinforcing bars should be tied to the roof plates, at intervals, by welding.

12. STEEL TOWERS. The Naval Facilities Engineering Command shall be consulted, on an individual project basis, for the criteria to be used for specific towers over 300 feet in height.

a. Freestanding Towers. Freestanding towers are subject to the following criteria.

(1) Geometry. Taper freestanding towers inward toward the top. For high towers, the tapering can consist of two or more slopes. The upper part of the tower can be uniformly shaped. Use a portal base only where functionally required (for access, or bringing in equipment, or to straddle an obstruction). Otherwise, connect the bottom struts to the tower legs close to the base.

(2) Foundations. Design foundations in accordance with *Soil Mechanics, Foundations, and Earth Structures*, NAVFAC DM-7, and to conform to the following requirements.

(a) Total base weight. Design the foundation so that the total base weight and any earth cover will equal at least 1.75 times the computed uplift at the top of the column base.

(b) Foundation weight. The minimum weight of the concrete foundation alone (not considering weight of the earth cover) shall equal computed uplift.

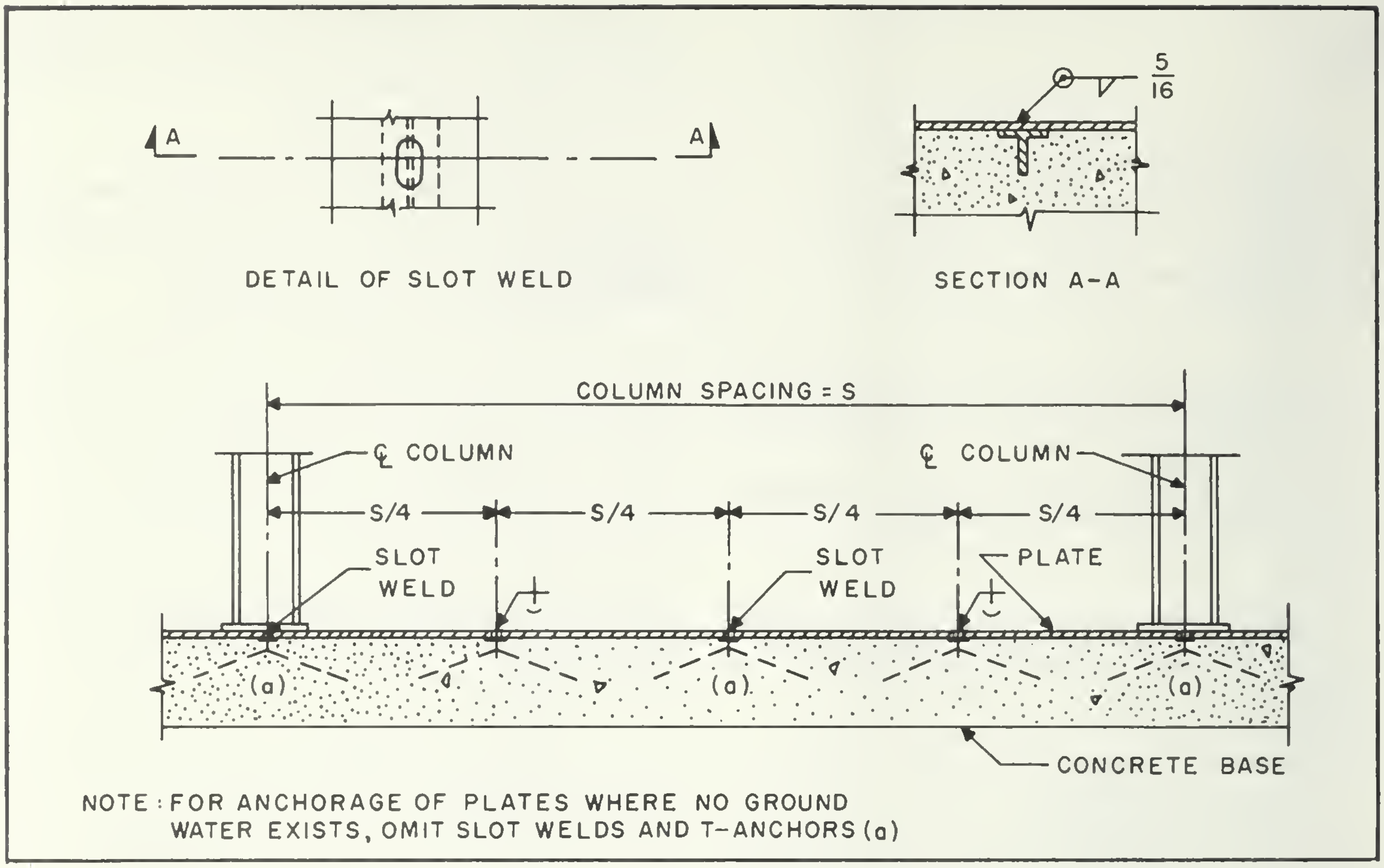


FIGURE 9-6
Floor Plate Anchorage for Underground Tanks with Ground Water

(c) Leg connections. Design the connections of legs to foundations for the computed uplift times 1.75.

b. Guyed Antenna Towers.

(1) Geometry. Guyed antenna towers with insulated bases usually are of constant cross section, due to electrical requirements.

(2) Guy Arrangements. No data are available at present for designing economically the number of guy levels for a tower or for determining the optimum guy slope. The factors to be considered are cost of guys including insulators, cost of mast, available real estate, electronic characteristics of structure, and available stock design or prefabricated towers or components. Three guys, at 120 degrees to each other in plan, usually are sufficient for one level of guying. More guys may be necessary because of the electrical characteristics of the antenna; these guys usually are radiating elements as well as structural supports.

(3) Elevation of Guy Attachments. Guy attachments should be placed in accordance with the following instructions.

(a) Single-guy layer. For a tower with a single-guy layer, place the cable attachments at about two-thirds of the tower height.

(b) Two-guy layer. For a tower with two-guy layers, place the cable attachments at about 0.3 and 0.8 percent of the tower height.

(c) Three-guy layer. For a tower with three-guy layers, place the cable attachments at about 0.25, 0.55, and 0.85 percent of the tower height.

c. Main Support Legs. When designing main support legs, the following should be considered:

(1) Triangular tower sections have a higher strength-to-weight ratio than square towers of similar height.

(2) The legs should be cylindrical in cross section for less wind drag, unless other factors dictate different cross sectional shapes.

d. Bracing.

(1) Tower bracing should provide diagonal bracing and horizontal struts in the plane of each tower face, for full tower height.

(2) If diagonal braces consist of single members, or form diamonds between horizontal struts, they shall be proportioned to carry either tension or compression loads.

(3) If braces consist of a pair of diagonals between horizontal struts, assume that shear will be resisted by tension diagonals, only.

(4) Provide horizontal braced frames (torsion frames) between tower faces every third or fourth panel for full tower height.

e. Design Assumptions. The following design assumptions should be made:

(1) Consider the tower as a beam-column on elastic supports. Elastic constants for supports are dependent on guy length, inclination, and material.

(2) Consider bending between guy levels and direct load due to vertical component of guy reactions.

(3) With no wind and air temperature at the design value, initial tension in guy cables shall be no more than one-tenth the rope breaking strength.

(4) There should be no increase of allowable stresses due to wind loading except as specified in item (6).

(5) Design factors to be used for guy cables and insulators, unless otherwise noted, shall be: guys equal 0.5 of manufacturer's guaranteed minimum breaking strength; insulators equal 0.3 of manufacturer's guaranteed minimum breaking strength; and eye bolts of "fail-safe" insulator equal 0.2 of manufacturer's guaranteed minimum breaking strength.

(6) Consider the effect of one guy broken with one-quarter wind load plus dead load, with an increase in allowable stress of 33 percent but not exceeding the yield of the material.

13. BOMB-RESISTANT AND BLAST-RESISTANT STRUCTURES. Obtain the latest criteria from the Naval Facilities Engineering Command. For collateral reading, see the Bibliography in this manual.

14. MISCELLANEOUS STRUCTURAL SYSTEMS OF STEELS.

a. Composite Construction. Composite construction is particularly useful where available construction depths are limited, or for increased stiffness. Basic criteria for composite construction are contained in Chapter 7.

(1) Composite action between slab and stringers will tend to occur naturally. Its natural occurrence is unreliable, however, and is normally insured by provision of special shear connectors. For types of shear connectors, see Figure 7-1.

(2) In continuous beams, full composite action occurs in regions of positive moment. Where negative bending moments develop, some reduction in section can be effected by considering the longitudinal reinforcement acting compositely with the steel.

b. Lally Columns. Lally columns are concrete-filled steel shells, available in round shapes of varying wall thicknesses with diameters of from 3.5 to 20 inches, or in rectangular shapes of various dimensions. Use these columns in areas where column dimensions must be limited, where dictated by architectural considerations, or where their use may decrease the time required for erection of building.

(1) Advantages. These columns are advantageous in steel frame or flat slab concrete systems with light loads.

(2) Problems. Consider problems of corrosion, maintenance (painting), and restricted fire ratings before selecting this system.

(3) Load Capacities. For load capacities, see manufacturers' catalogs.

c. Grid Framing Systems. Grid systems comprise intersecting equally spaced members forming parallelograms (Figure 9-7). Concentrated loads are directly distributed to adjoining members. This system is used in gratings for walkways and stair treads. Larger assemblies, utilizing welded web plates or rolled shapes with or without steel cover plates, may be used for floor systems of high load capacities. Fabrication costs are high except for commercially available gratings. Savings in material costs are offset by complicated welding, warping, cutting, and other difficulties. Marginal beams and end diaphragms shall be provided.

d. Sheet Pile Structures. Criteria for sheet pile structures are contained in *Soil Mechanics, Foundations, and Earth Structures, NAVFAC DM-7.*

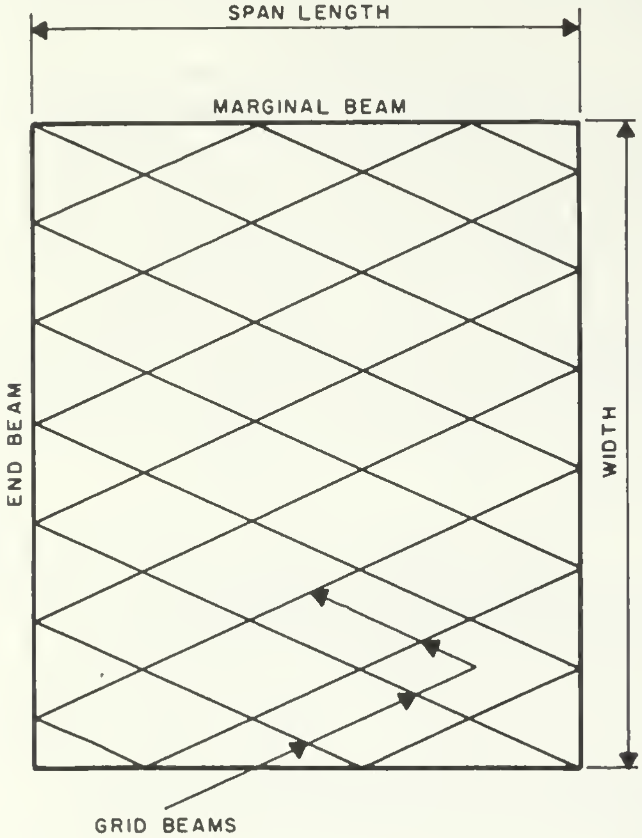


FIGURE 9-7
Grid System

Section 4. CONCRETE STRUCTURAL SYSTEMS

Part 1. CONCRETE FLOOR FRAMING SYSTEMS

1. **BEAM AND GIRDER FRAMING.** Typical beam and girder framing is illustrated in Figure 9-8.

a. Application. Beam and girder framing is applicable for heavy loadings common to industrial buildings or in areas where framing is discontinuous because of shafts, stairs, and ducts and for concentrated loads, with additional beams as required.

b. Framing Details. The following directions apply:

(1) Place beams on 6- to 12-foot centers.

(2) Place columns on 18- to 25-foot centers.

(3) Standardize beam sizes for maximum reuse of forms.

(4) Consider reduction of end slab spans to maintain constant slab thicknesses.

2. **ONE-WAY AND TWO-WAY SLABS.**

a. Applications.

(1) Use two-way slab framing for larger spans, unless architectural considerations or building code requirements dictate otherwise.

(2) Usually, the choice between a one-way or a two-way slab system is dictated by laying out the beam and girder framing, the panels between beams, and girders being reinforced in accordance with the length-to-width ratio.

(3) A combination of one- and two-way systems is applicable where the structure consists of a narrow corridor separating workspaces (hospitals, schools, and similar constructions), as shown in Figure 9-9.

(4) Two-way systems are required for medium to heavy live loads on spans in excess of 12 to 15 feet.

b. Framing. Usually, one-way slab systems are used with spans of 6 to 15 feet. Usually, two-way slabs are required for larger spans.

c. Supports. The supports may be beams, girders, or bearing walls, as illustrated in Figure 9-10.

3. **FLAT SLAB, FLAT PLATE, AND SLAB BAND.**

a. Flat Slabs. Flat slabs have no supporting beams except at the edges, and rest directly on column capitals. A thickened section of slab can be used around the capital to increase shear area. Such a slab section, termed a drop panel, is shown in Figure 9-11. Flat slabs are suitable for medium to heavy distributed loads on 20- to 35-foot panels. Omission of beams and girders allows lower story heights for multistory construction with consequent economies. Formwork is simple with numerous reuses possible.

b. Flat Plates. Flat plate floors are similar to conventional flat slabs but without column capitals, brackets, or dropped panels. Ceilings are smooth and unobstructed, slab and column forms are simpler, and story heights can be reduced more than with flat slabs. Flat plates are suitable

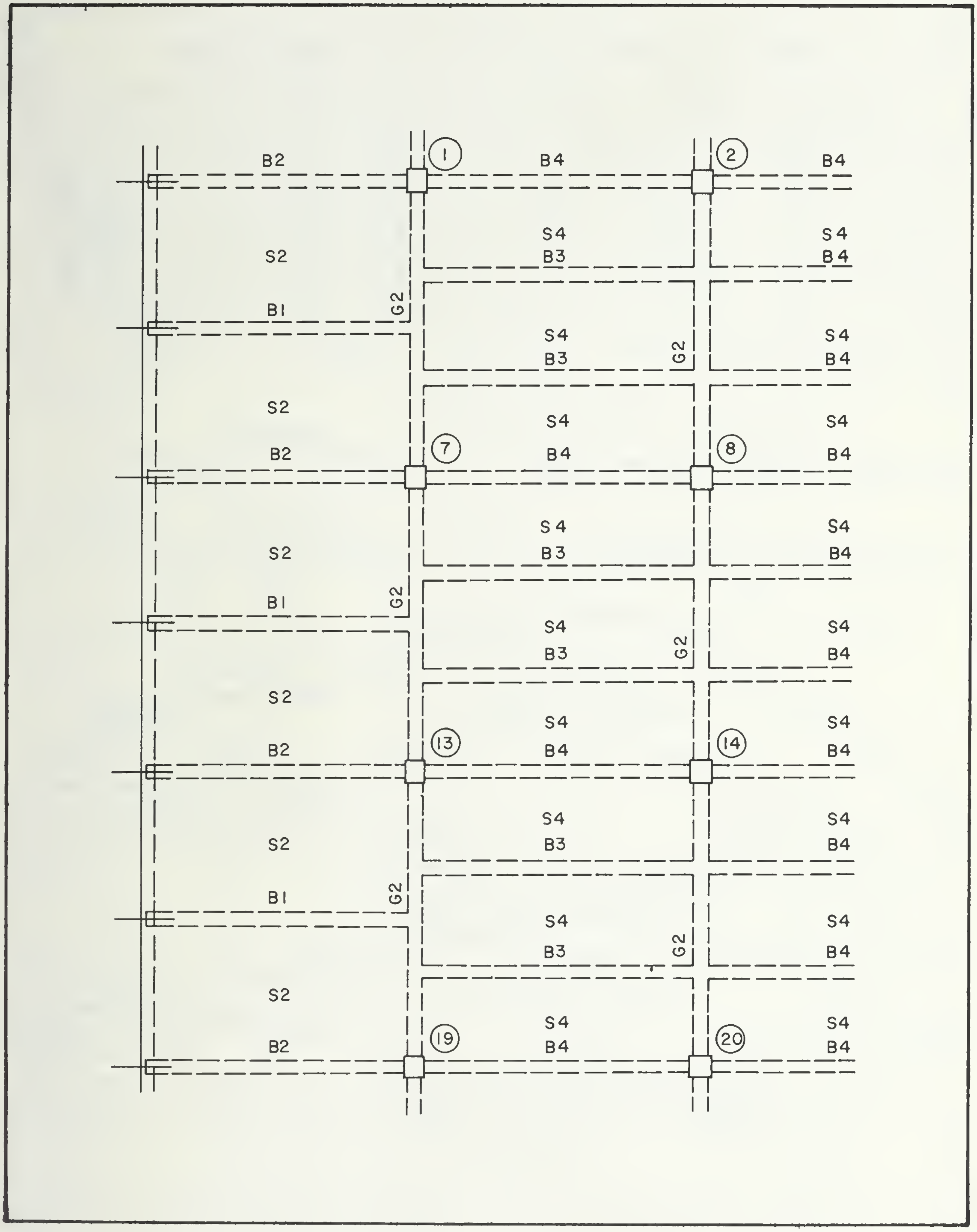


FIGURE 9-8
Beam and Girder Framing Plan

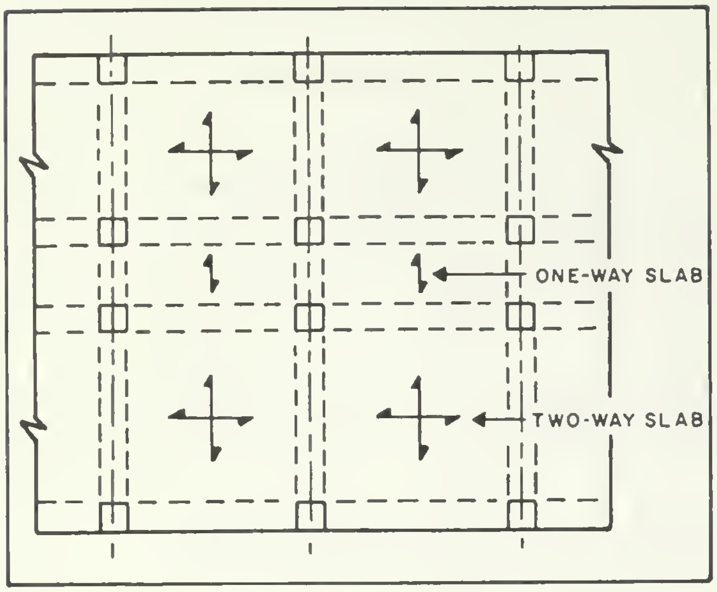


FIGURE 9-9
Two-Way Slab in Combination With One-Way Slab

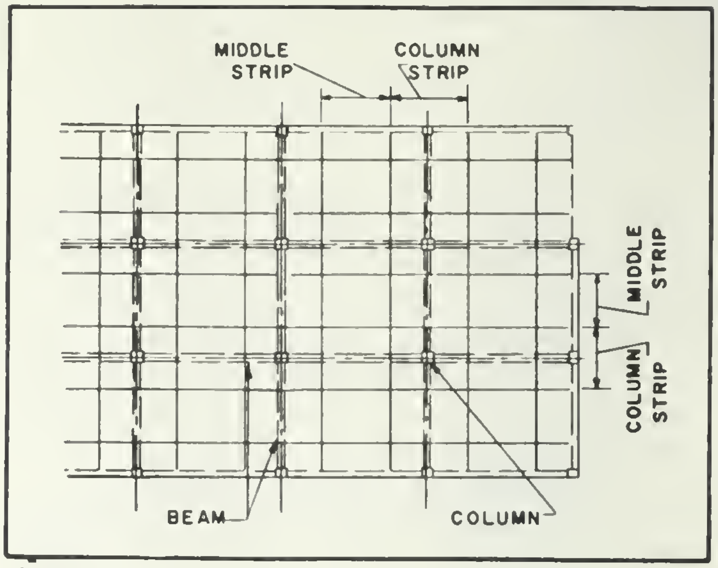


FIGURE 9-10
Two-Way Slab Framing Plan

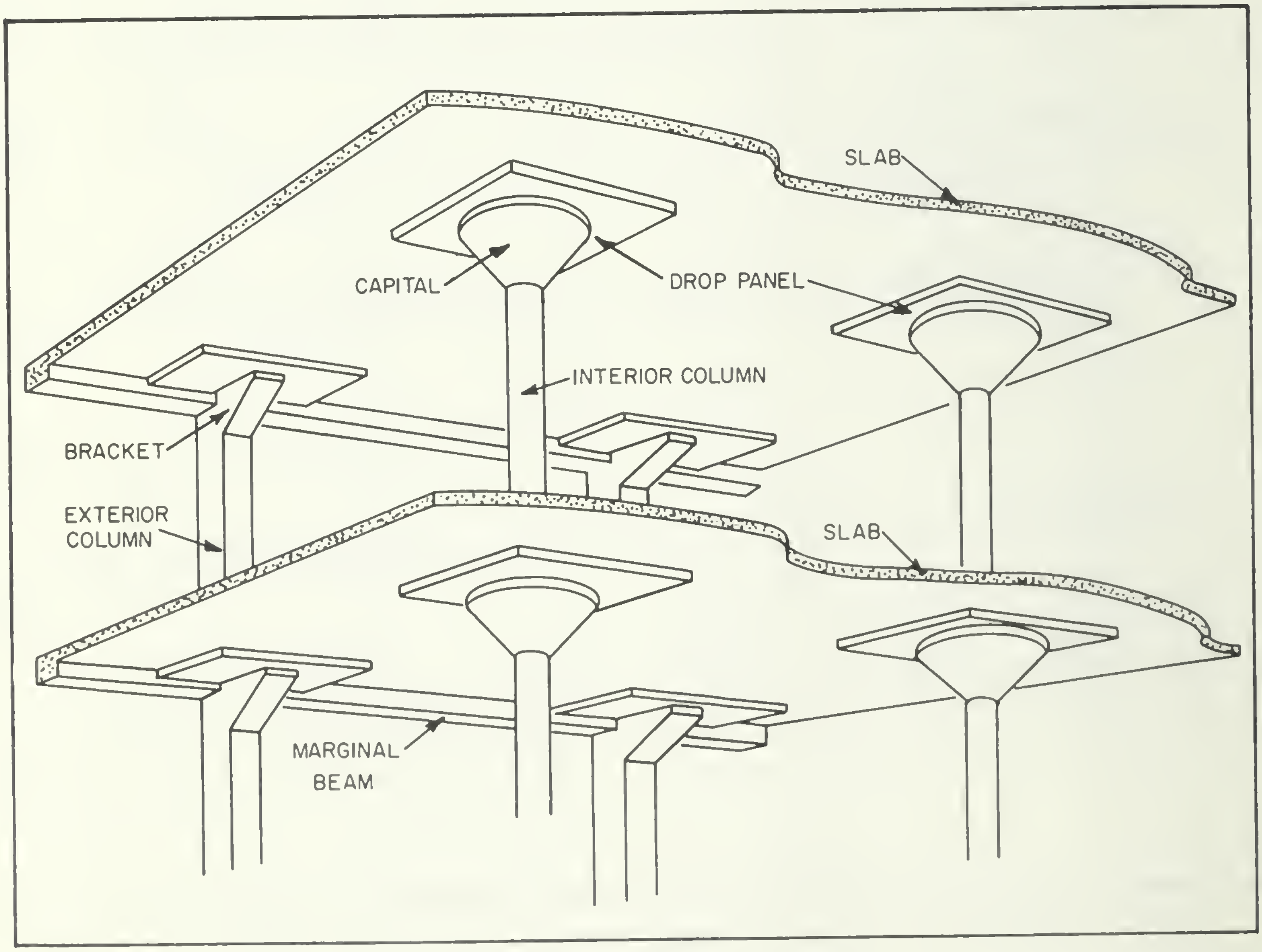


FIGURE 9-11
Flat-Slab Construction

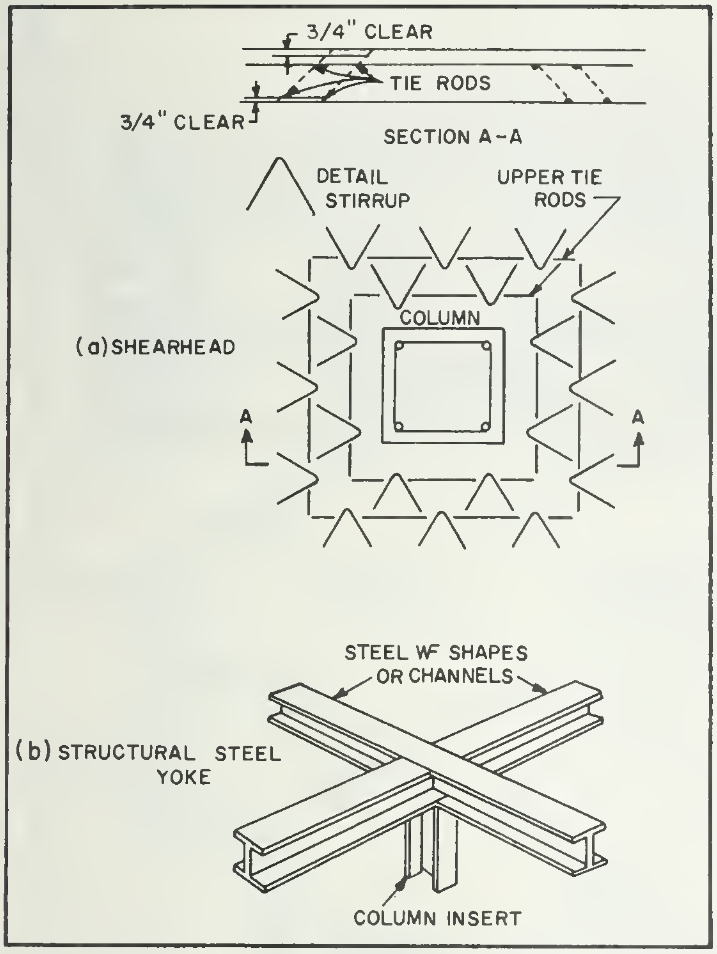


FIGURE 9-12
Built-In Column Capitals

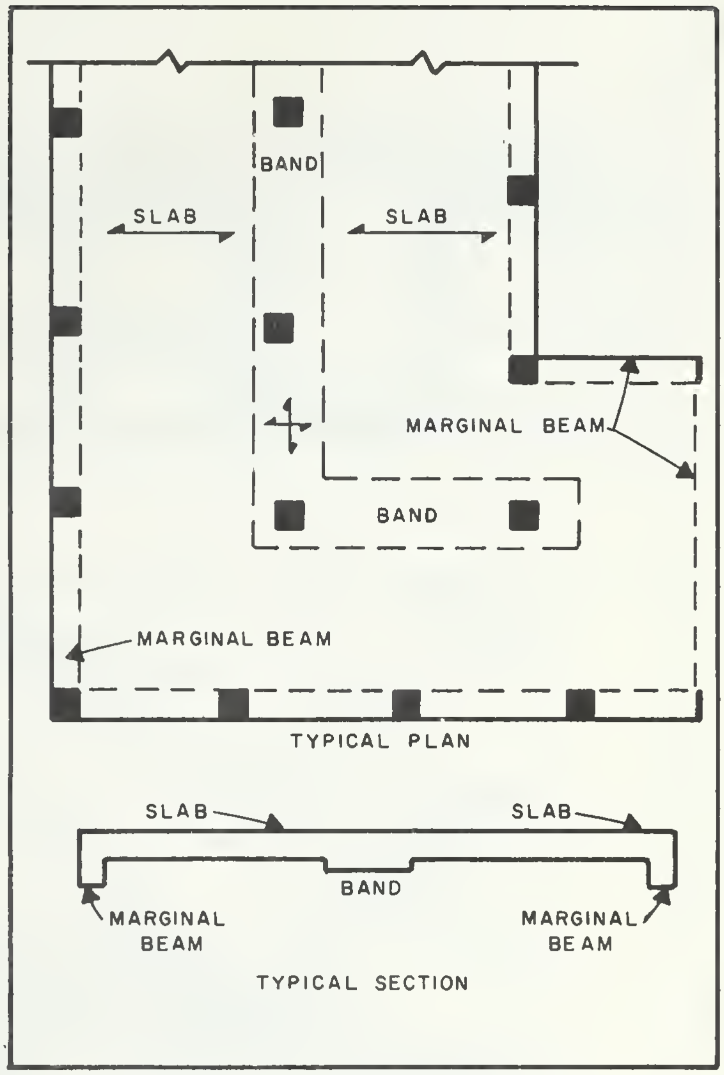


FIGURE 9-13
Slab Band Floor

for light to medium distributed loads on 18- to 35-foot panels. Avoid pipe or duct openings near columns. Built-in shear heads can be used where required by shear stress at columns, as shown in Figure 9-12.

c. **Slab Bands.** Slab band floors consist of a continuous one-way solid slab between bands or shallow, wide beams. They are reinforced in two directions, but transmit their loads in one direction only to supporting columns. Figure 9-13 illustrates a typical slab band floor. At the slab periphery, bands become marginal beams. This system is useful where column spacing is irregular. Columns need not line up, but should be within the band.

4. **RIB SLABS.** Concrete slabs can be made more efficient or lighter by removing concrete from the tension areas of the bottoms of the slab. This can be accomplished by the use of permanent or removable fillers forming either one-way or two-way ribbed panels. Leave a solid (unribbed) section around the column heads for shear resistance.

a. **Permanent Fillers.** Place solid fillers (hollow permanent blocks of clay tile, lightweight concrete blocks, or gypsum) in the slab bottoms. Space fillers at regular intervals to form Tee beams within the slab. Omit entirely in special sections to allow solid slabs under load concentrations; for example, at partitions or at column heads. In Figure 9-14, tiles are applied to produce a uniform slab soffit for a plaster ceiling. In Figure 9-15, concrete blocks of lightweight aggregates are utilized. Concrete block fillers are used in Figure 9-16.

b. **Removable Fillers.** Make removable fillers of steel, fiberboard, or cardboard pans that are commercially available in various sizes and depths.

(1) One-Way Systems. For one-way systems, tapered end pans can be used to increase rib thicknesses at end of spans where shear

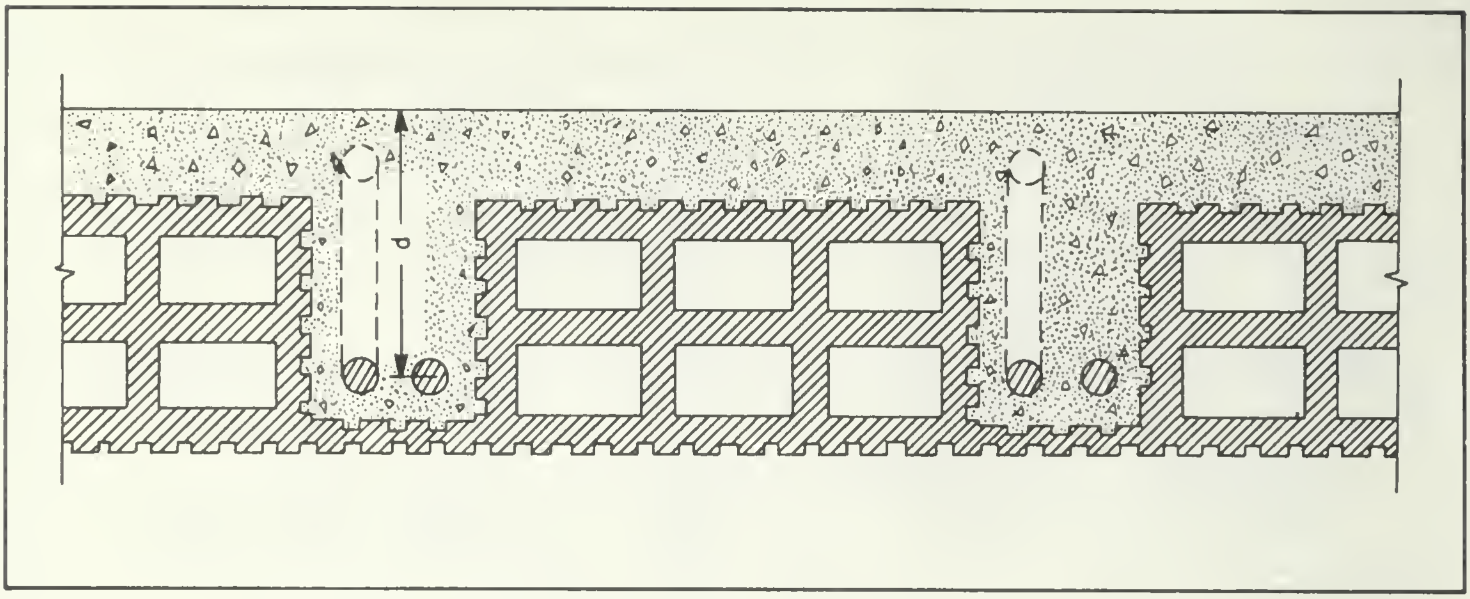


FIGURE 9-14
Tile Fillers with Soffit Tiles

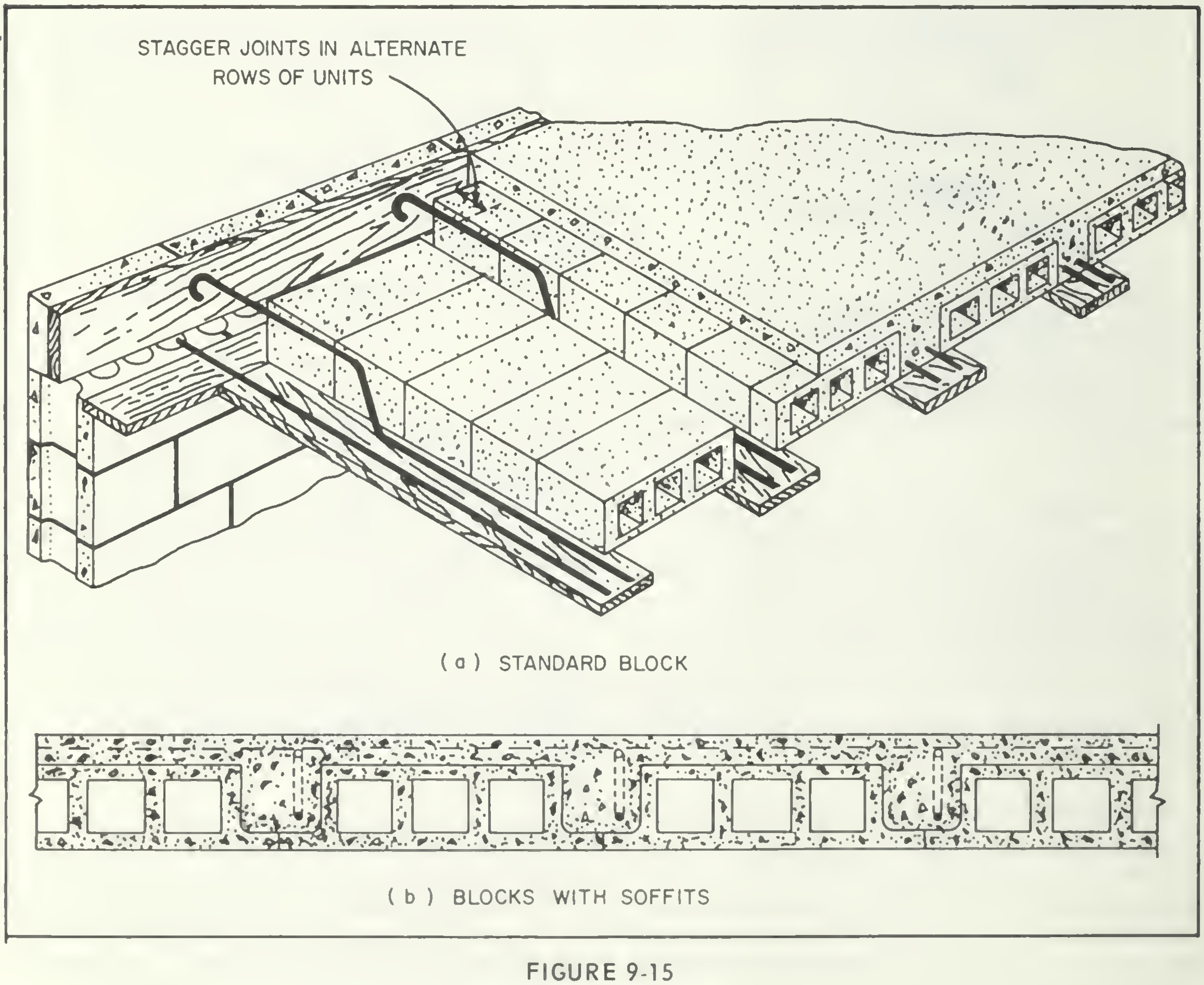


FIGURE 9-15
Concrete Block Fillers .

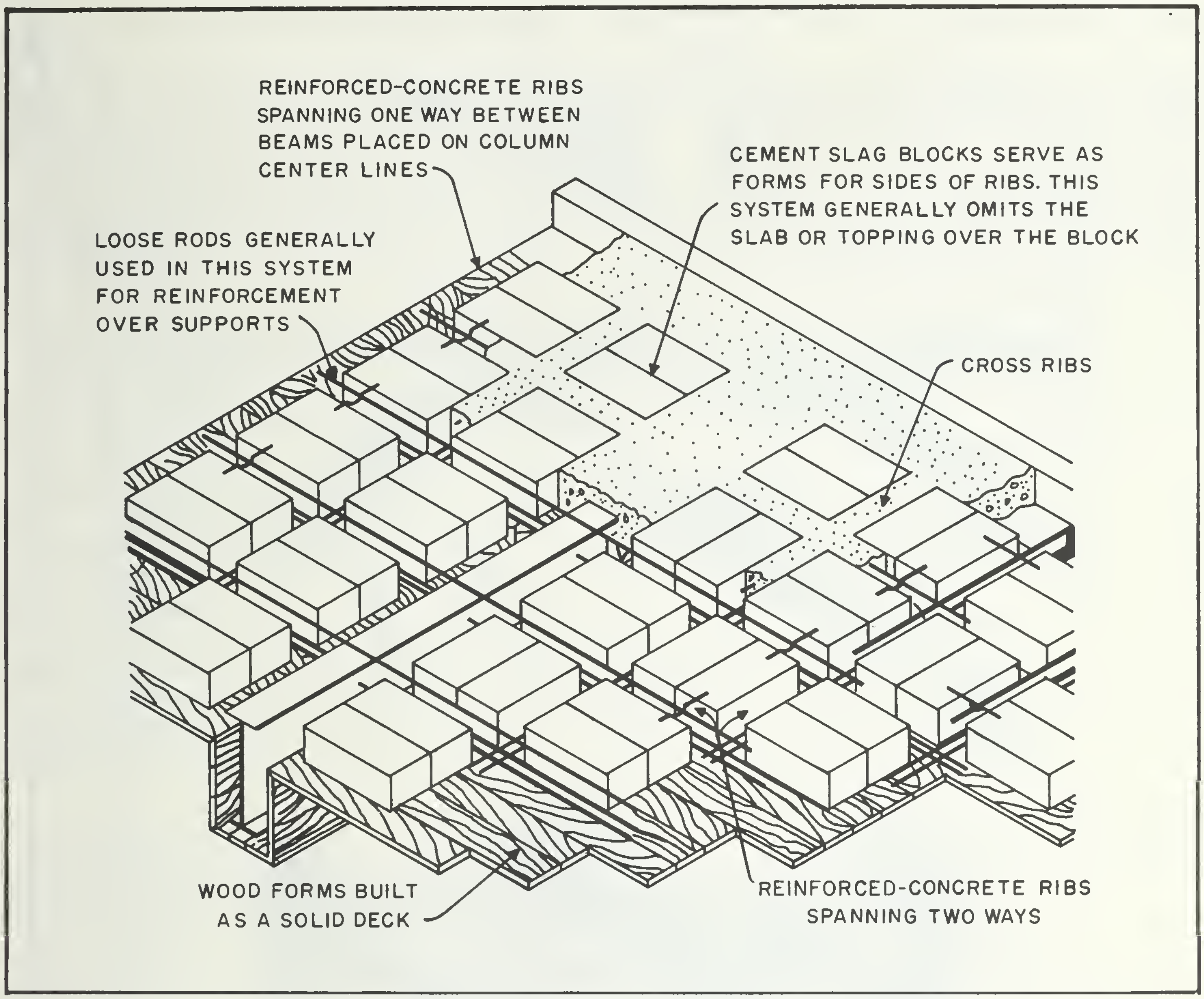


FIGURE 9-16
Slag-Block System

stresses are high. Form work is simple and need not be a solid deck.

(2) Domes. Domes may be similarly employed for two-way or flat slabs (Figure 9-17).

5. **LIFT SLABS.** Lift slabs are flat plate slabs cast in succession on the ground and subsequently lifted into place in the structure. Each slab serves as the casting bed for the succeeding floor. Columns usually are rolled steel shapes. Special shear connections are required between columns and slabs. There is little form work, but the system requires precise erection methods and special equipment. The size and weight of lift are limited and the system usually is restricted to applications where loads are light to moderate. To minimize slab deflections during erection, control lifting by a hydraulic jack console. Lift slabs are suitable for multiple-story construction where floor slabs are identical. The principal advantages are reduction in form work and rapid construction. These savings, however, are offset by the cost of special equipment.

6. PRECAST CONCRETE CONSTRUCTION.

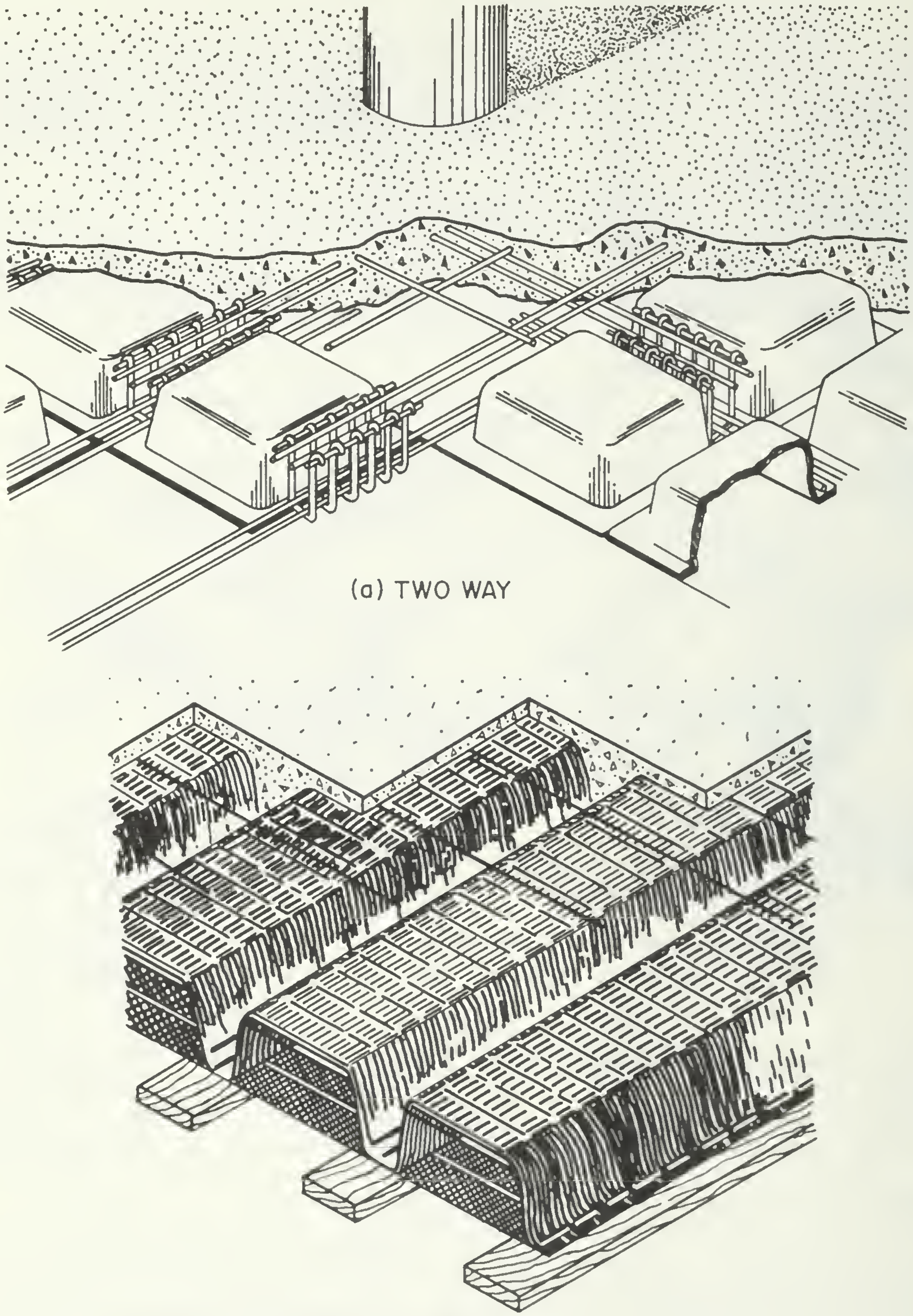
a. Advantages. Advantages of precast concrete construction are:

(1) Simplifies form work and eliminates shoring.

(2) Permits multiple use of forms.

(3) Makes for easy handling and placing of reinforcements.

(4) Allows for assembly line operations.



(a) TWO WAY

(b) ONE WAY

FIGURE 9-17
Metal Pan Rib Slabs

(5) Is not subject to delay due to weather conditions.

(6) Permits better finishing and curing than cast-in-place construction.

(7) Produces uniformity of product.

(8) Provides accuracy of dimensions.

(9) Permits use of higher strength concrete (due to controlled manufacture) than with cast-in-place construction.

b. Disadvantages. Disadvantages of precast concrete construction are:

(1) Pieces may be damaged during handling and erection.

(2) Size is limited by shipping methods, distances to sites, and lifting facilities.

(3) Continuity at connections is difficult to attain without special designs and details.

(4) Lifting and erection stresses may present problems.

(5) Construction is not suitable for irregular framing or for applications lacking in repetition.

(6) Construction does not provide transverse continuity (that is, does not function as a diaphragm) unless joints are specially detailed.

c. Floor Panels. Large, heavy, precast panels in widths of from 4 to 8 feet and lengths of from 16 to 30 feet are advantageous where erection is practical with available equipment. These large components can be used in particular projects as substitutions for the commercial precast planks as follows; also see Figure 9-18. For connections and joints, see Figures 9-19 and 9-20.

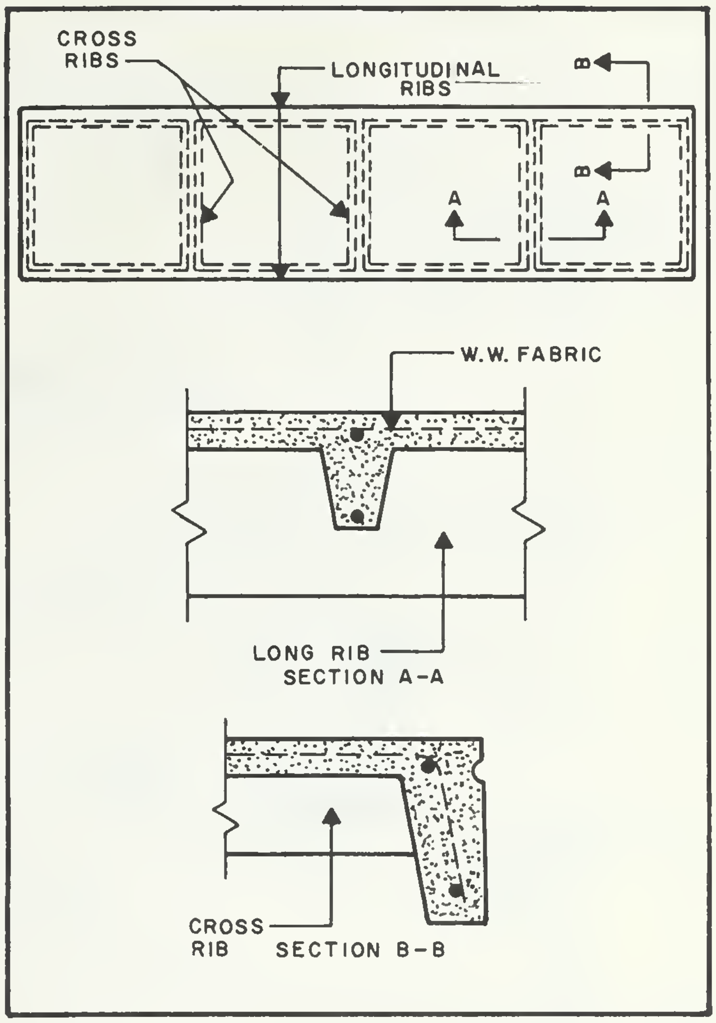


FIGURE 9-18
Typical Precast Floor Panel

d. Planks. Narrow planks, 12 to 24 inches wide, are commercially available in many materials. They are obtainable in stone concrete, lightweight concrete of various aggregates, nailable concrete, and in combinations with attached insulation and soundproofing.

(1) Load Capacities. Load capacities vary from 40 to 150 psf. Spans vary from 2 to 20 feet (depending on type and depth).

(2) Precast Planks. Precast planks, as shown in Figure 9-21, are used most frequently with steel-framed structures and to support distributed loadings. They usually are not suitable for support of concentrated or line loads, and the shear should be checked wherever they are being considered for use with concentrated loads.

(3) Anchorage. Provide positive anchorage to supporting members as shown in Figure 9-19.

e. Frames, Beams, and Columns. Major members shall be adequate in sizes and rigidities to resist erection as well as design loads. The following considerations and requirements apply.

(1) Consider use of hollow, cored, or shaped sections to reduce weight (use fiber tubes or bolt-together channel shaped halves). See Figures 9-22 and 9-23 for details.

(2) Usually, welding and grouting are used to form splices to main members or connections between joining members.

(3) Locate splices at areas of minimum stress. Examples are shown in Figures 9-24 and 9-25.

(4) Limit units to size and weight which can be handled with conventional equipment.

(5) The use of lightweight aggregates in columns is not recommended.

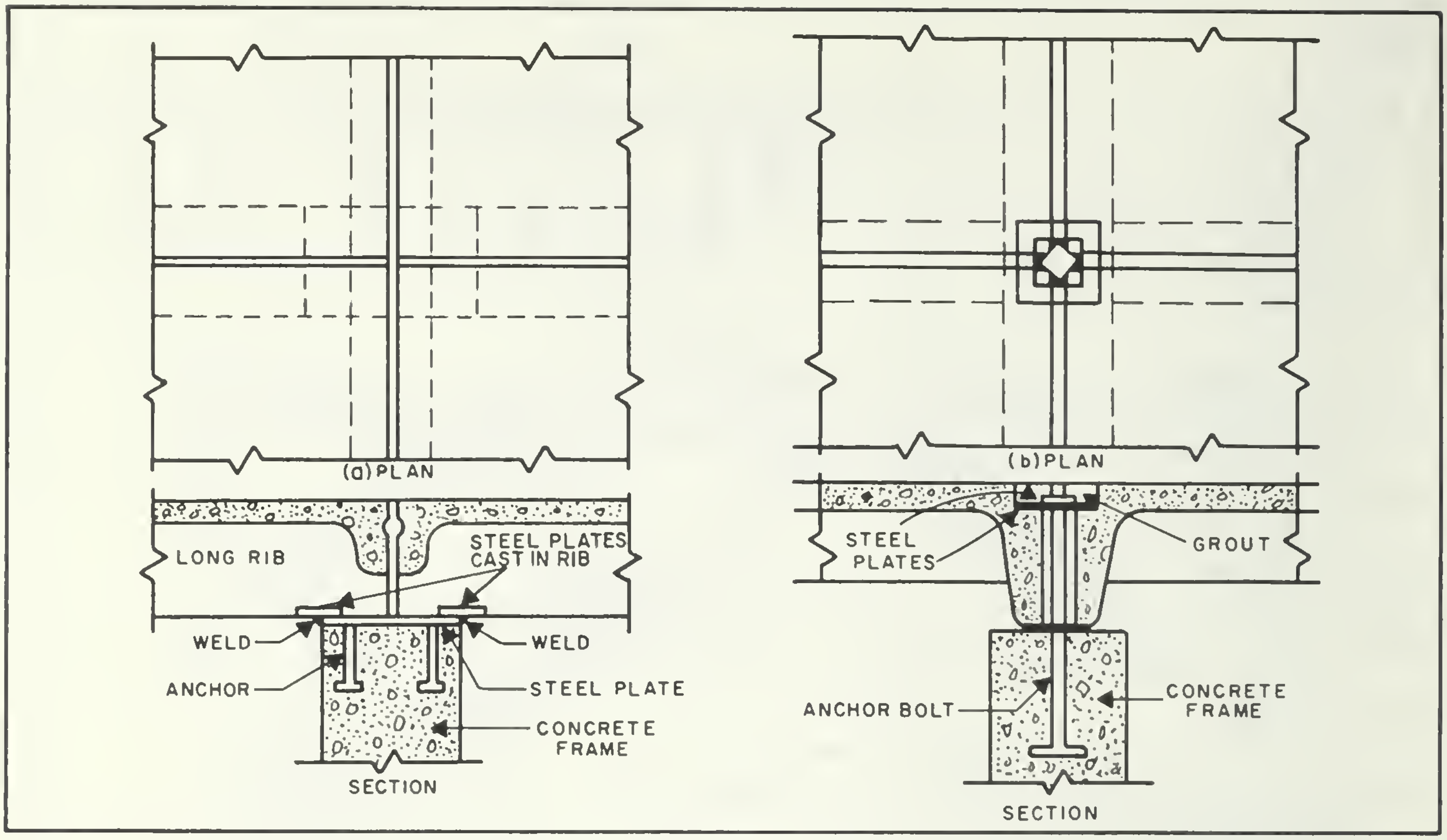


FIGURE 9-19
Fastening Precast Panels to Frame

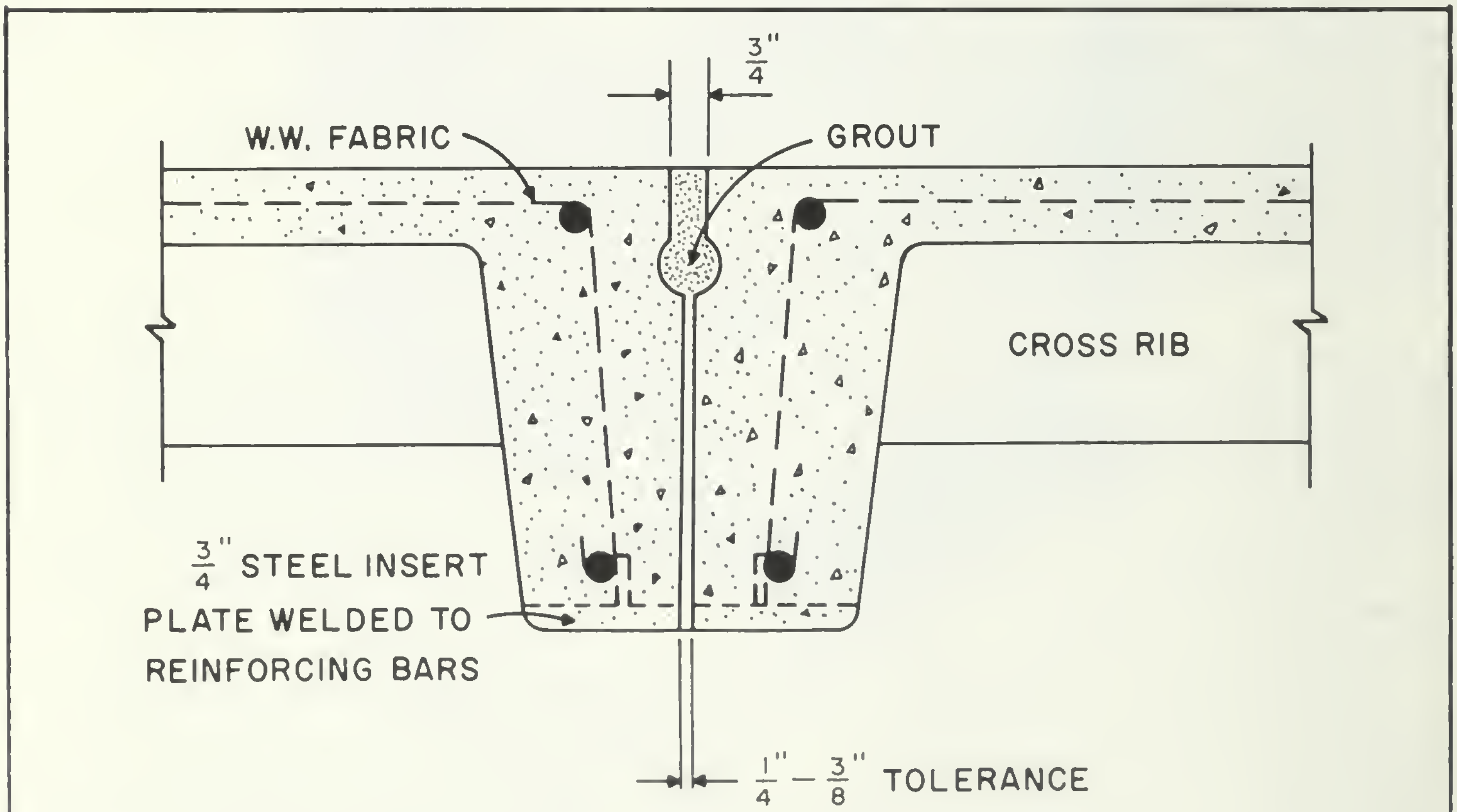


FIGURE 9-20
Typical Seam Between Precast Panels

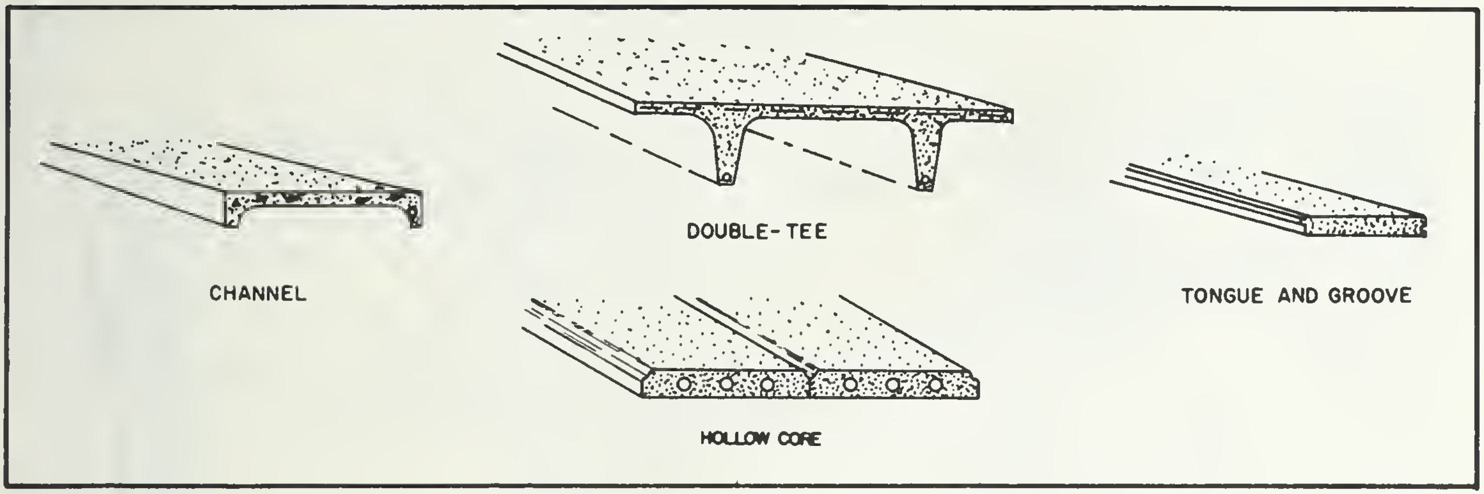


FIGURE 9-21
Typical Precast Planks

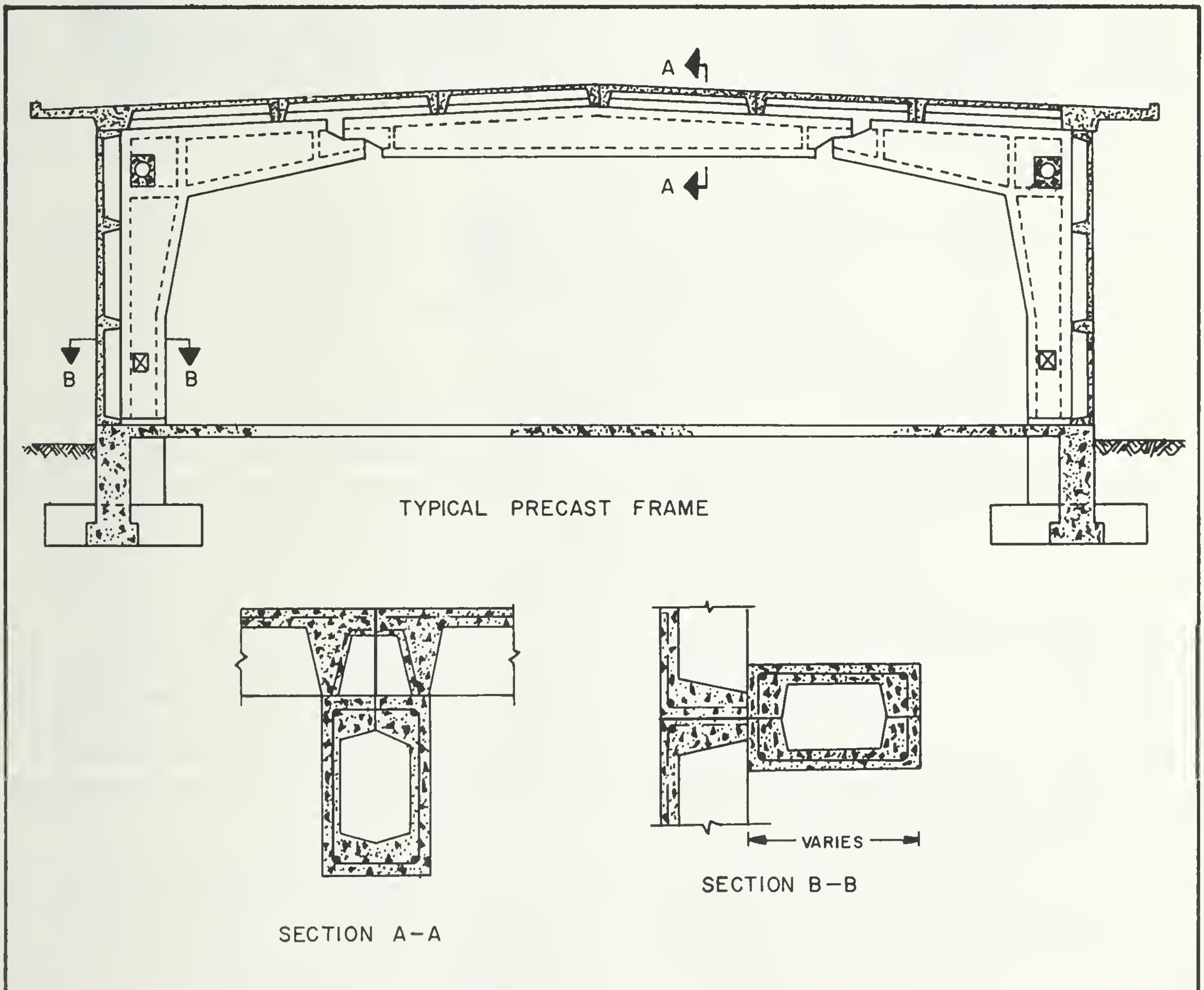


FIGURE 9-22
Typical Precast Concrete Single Bay Rigid Frame Building

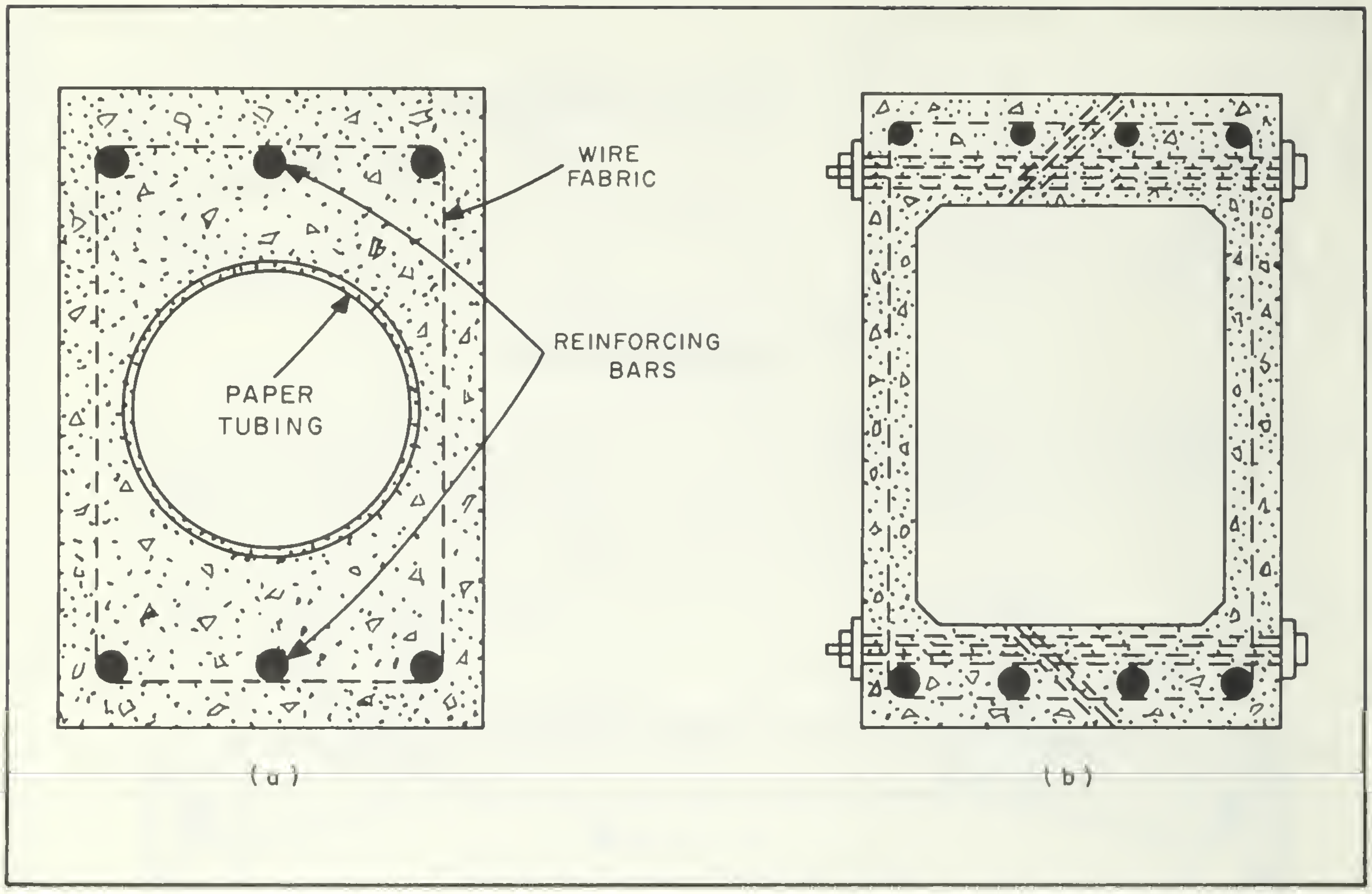


FIGURE 9-23
Typical Section of Main-Bent Members

f. **Wall Panels.** Where there is a large amount of repetition of wall panels and where a structure is one story high, the use of precast panels, tilted up into place, is frequently economical.

7. PRESTRESSED CONCRETE.

Prestressed concrete components can be stressed by pretensioning, posttensioning, or a combination of both of these methods.

a. **Pretensioning.** Pretensioning usually is used where large numbers of precast units of similar size or shape are required. One or more tension beds are required. The procedure consists of placing long lengths of high tensile strength wires or strands, tensioned by hydraulic jacks, in the member forms, and placing concrete around the wires. Various lengths of members may be made by inserting bulkheads or spacers at intervals on the forms. Precast slabs, joists, and beams in this form are commercially available. Special shapes can be made for any particular structure.

b. **Posttensioning.** In posttensioning, steel strands are inserted through ducts cast inside members by using sheet metal tubing, flexible metal hose, or removable rubber core units. After strands are stressed and mechanically anchored, the ducts are filled with grout. Posttensioning is applicable to: poured-in-place construction; pieces too large or heavy to transport; long span and continuous structures, in lieu of draping the wire strands; precast elements, where the number of pieces does not justify the cost of the transioning bed; joining together precast elements; and to composite sections.

8. PRECAST WALL CONSTRUCTION (SANDWICH AND RIB PANEL).

Precast panels may be considered for use as spandrel facings or for full story height walls in either steel or concrete framed structures.

a. **Exterior Walls.** Exterior walls should be moment- and shear-resistant frames or panels.

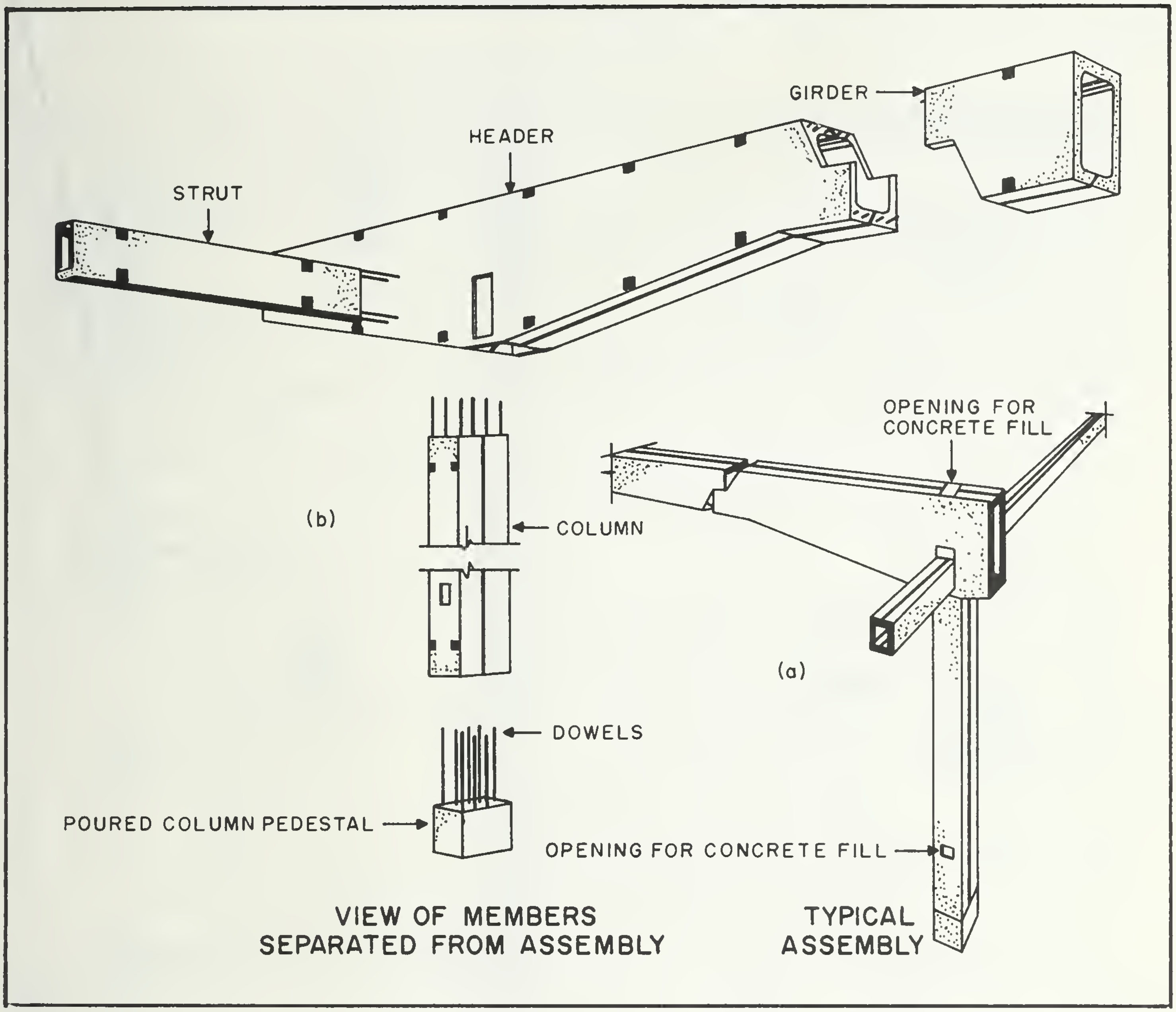


FIGURE 9-24
Assembly Details of Precast Concrete Construction

This construction eliminates the need for unreinforced bricks or cinder blocks. Precast exterior wall panels are sandwich or rib types.

(1) In sandwich-type walls, place insulation between two thin concrete slabs connected by continuous edge concrete to cover insulation.

(2) The two surface layers should be connected by adequate shear reinforcing.

b. **Panels.** Figure 9-26 provides details of a sandwich wall panel with foam glass insulation. Recently there has been a trend toward use of special aggregate in lieu of insulation. Figure 9-27 contains details of a ribbed wall panel for warehouse construction. The lower portion of slab (section c-c) is made thick to guard against damage by trucks or fork lifts.

(1) Connections between precast panels and frames may be made by welding metal inserts in the roof to similar inserts cast in supporting members, or by bolting, as shown in Figure 9-28.

(2) Use relatively rigid framing rather than masonry for interior shear walls.

(3) Provide adequate anchorages or connections between partitions and framing.

9. **OFF-THE SHELF SYSTEMS.** Many precast and prestress units are available as manufacturers standard items, including some patented systems.

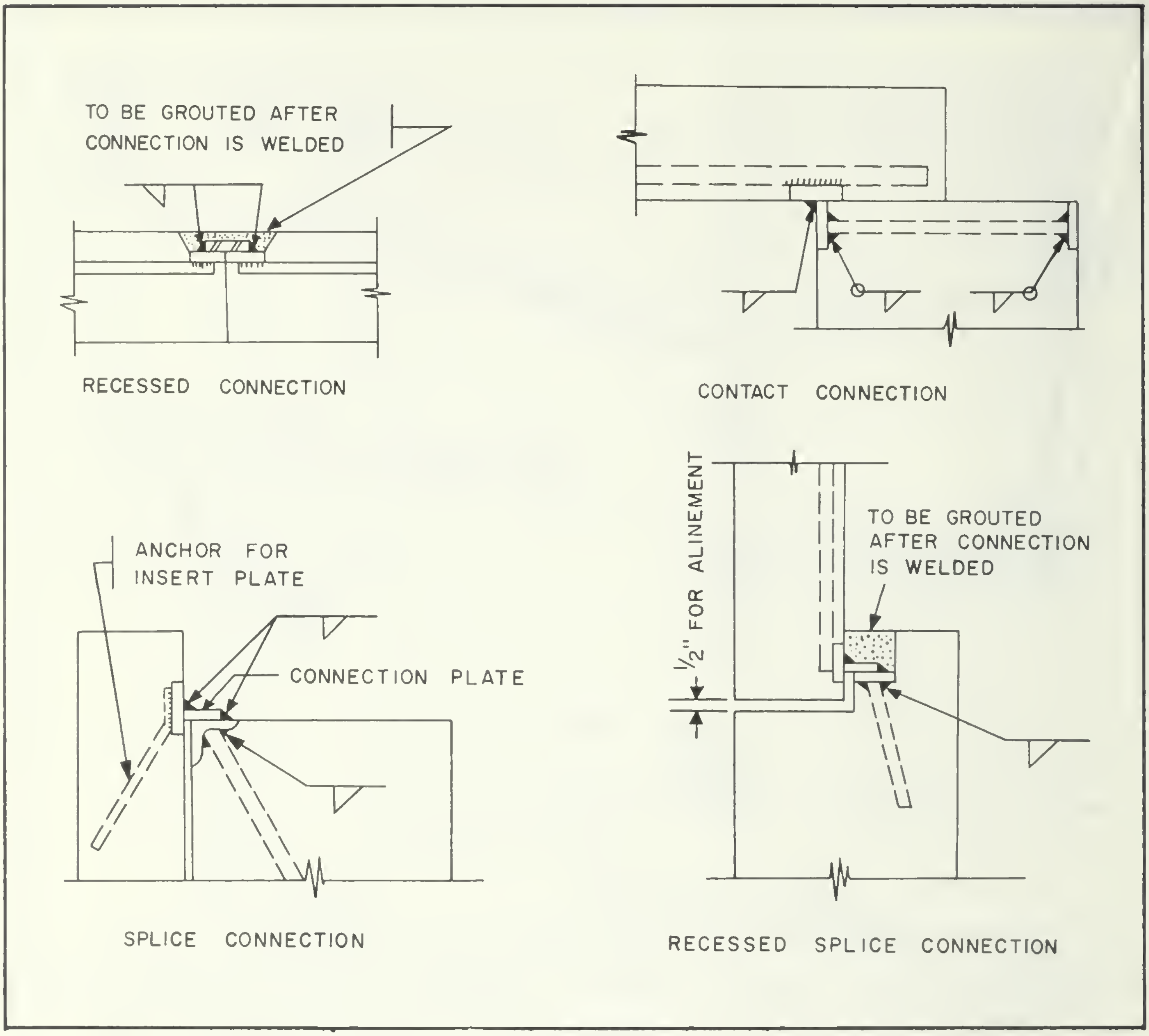


FIGURE 9-25
Types of Insert Connections

Use of such items, where available, will often be more economical than new designs.

Part 2. CONCRETE ROOF FRAMING SYSTEMS

1. **FLAT ROOFS.** Use the same type of construction as used for floors, Section 4, Part 1, to reduce costs. All floor framing systems usually are applicable to flat or slightly pitched roofs. For criteria on exposed concrete roof slabs, see Section 3.

2. **PITCHED ROOFS.** The following sloping roof structures can be used on single-story buildings with large spans over areas free of columns.

a. **Roof Trusses.** Concrete roof trusses have limited applications and their use is not encouraged. Vierendeel trusses (Figure 9-29) can be used, but are more applicable to steel construction.

b. **Rigid Frames.** Rigid frames may be used for all moderate spans incorporating either precast elements (pretensioned or posttensioned) or ordinary cast-in-place construction. Advantages are similar to those listed for steel rigid frames.

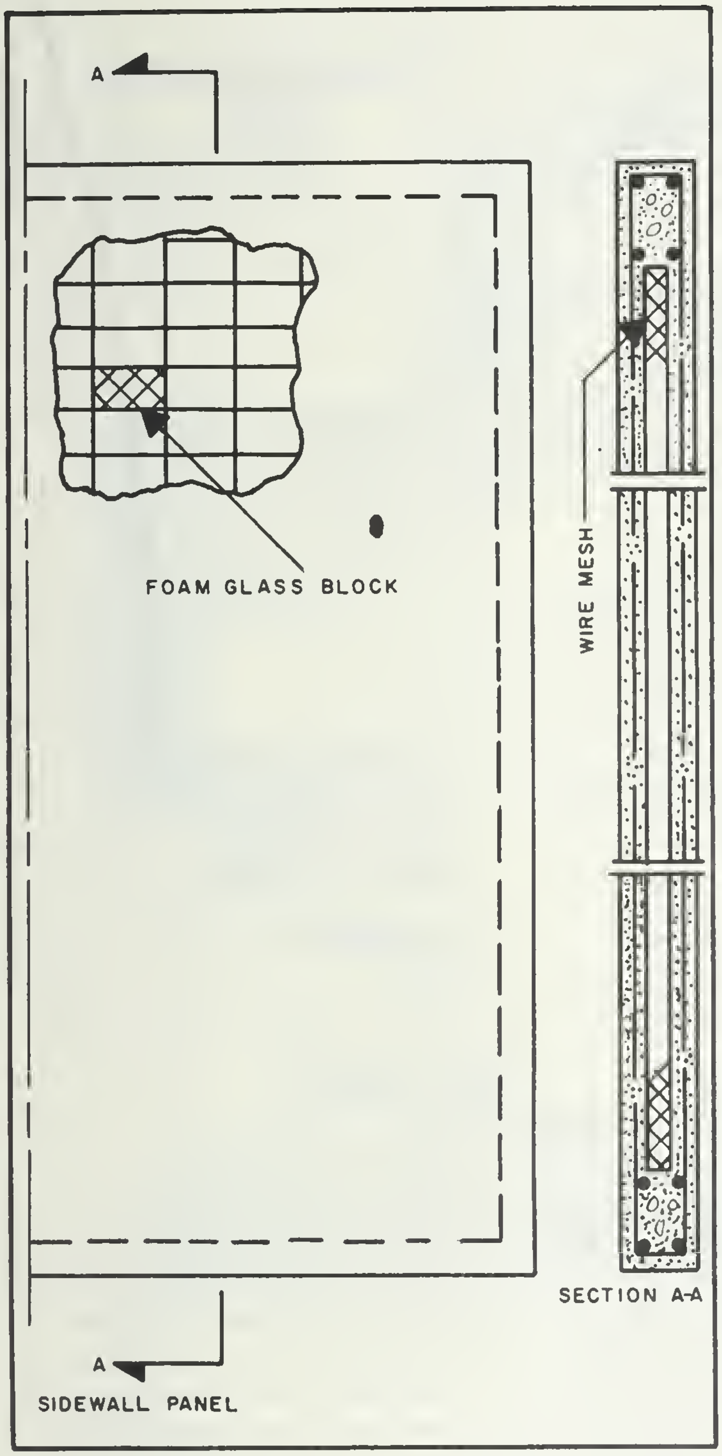


FIGURE 9-26
Details of Precast Concrete Sandwich-Type Wall Panel

(1) Vary types, sizes, and overall shapes to suit architectural requirements.

(2) Usually, rigid frames are used for spans between 60 and 100 feet. Shorter spans may be desirable for reasons other than economy. For single and multiple span rigid frames, see Figures 9-30 to 9-32, inclusive.

c. Arches. Use arches, generally as the most economical framing, for spans of more than 120 feet.

(1) The arch axis should follow the pressure line corresponding to dead load plus one-half live load.

(2) Arch types are the same as those listed for steel arches. Selection factors are similar to those for steel structures except that it is desirable to use the fixed type, where possible. Unless specially detailed and maintained, hinges in concrete structures seldom function satisfactorily.

(3) Ribs can be case in hollow box sections to save weight and reduce shrinkage, or in pairs of channel shapes, bolted or welded together by metal inserts.

(4) Precast arch rib segments should be in lengths consonant with available equipment for handling and erection. Sections shall be joined by lap-welding the reinforcing steel of adjacent members and grouting pockets in sections.

d. Thin Shell Construction. Thin shells are characterized by a large span-to-thickness ratio and by surfaces curved or sloped in one or more directions. The stress on the material is usually relatively low if the still form is properly designed. Use of thin shells should be considered in the design of those facilities where large unobstructed spaces are desirable.

(1) Types of thin shells are barrels, hyperboloids, paraboloids, domes, folded plates, and modifications and combinations of these types. (See Figures 9-33 and 9-34.)

(2) Material can be reinforced concrete, steel, wood, plastic, or aluminum. Precast concrete units should be considered. The desired objective is to use a minimum number of different shapes which can be easily mass-produced in a shop.

(3) Special consideration should be given to maximum economy by use of simple curves, uncomplicated intersections, repetition of individual elements, and a minimum of form work. In addition, direct stresses usually are low. In most concrete shells the minimum thickness is determined by construction requirements, such as concrete cover over reinforcement and construction tolerances.

(4) In addition to determining stresses caused by dead, live, wind, and seismic loads, the stresses resulting from temperature changes and variation in moisture content shall be investigated. Also investigate secondary stresses such as uniform volume change of the rib and the shell, differential volume change between the rib and the shell, rib shortening, and unequal settling of footings.

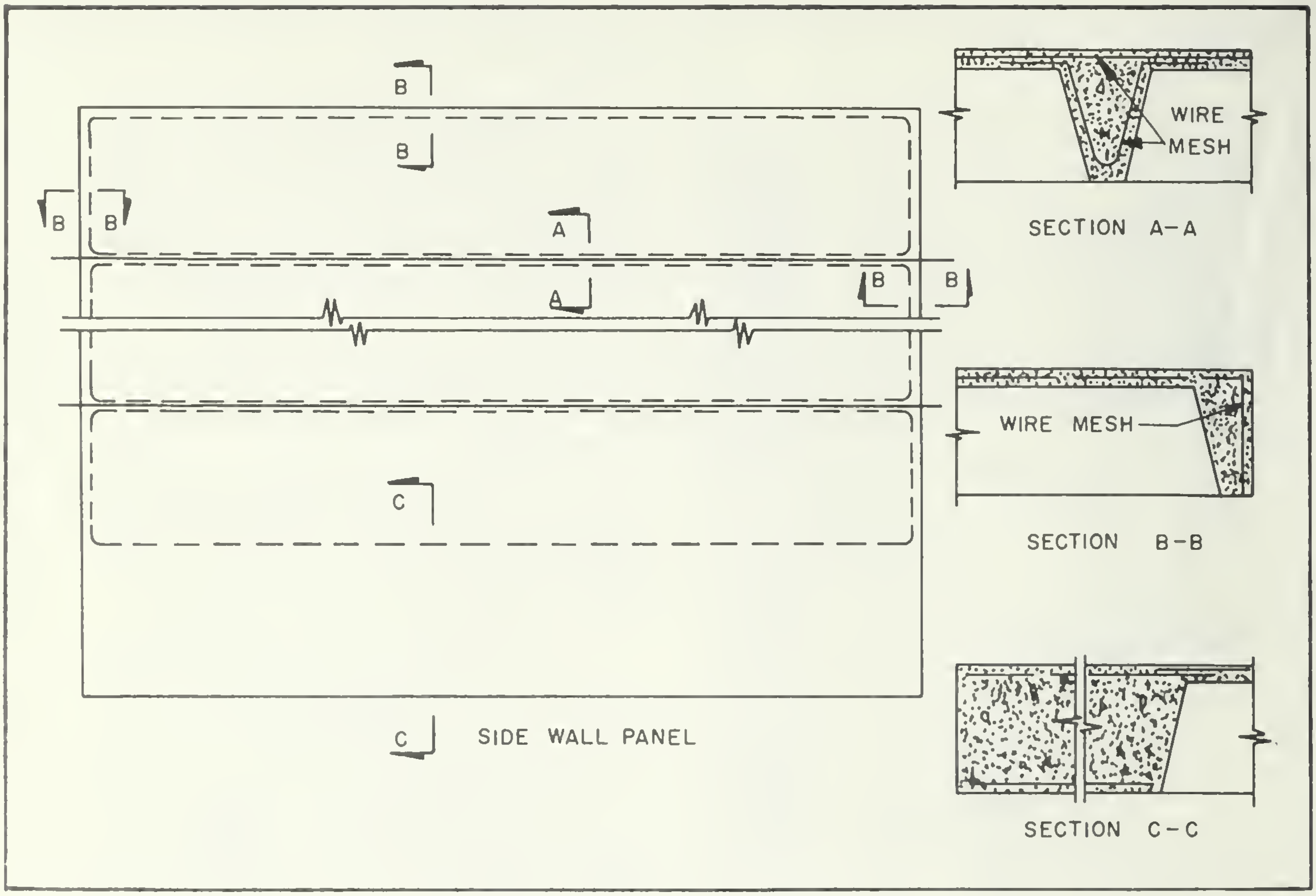


FIGURE 9-27
Details of Precast Concrete Ribbed-Type Wall Panel

(5) No code exists for thin shell construction. Compressive stresses usually are limited to a small percentage of the allowable values given in the ACI Building Code. Current practices, as reported in the technical papers and similar literature on the subject, should be reviewed in detail prior to initiation of design.

(6) Problems existing in weatherproofing thin shell structures have not been solved completely. Available lists and literature should be reviewed prior to selection of a framing system.

(7) For sources of design data for thin shells, see the Bibliography for ASCE, ACI, Portland Cement Association, AISC, American Plywood Association, and current technical data published on the subject.

Part 3. CONCRETE MULTISTORY RIGID FRAMES

1. DISCUSSION. Multistory structures require bracing against lateral loads. Bracing can be accomplished by the use of shear walls, braced bays, or moment-resistant connections between beams and columns. Where the use of shear walls or braced bays is undesirable because of architectural or functional requirements, the use of multistory rigid frames is indicated. Also, this system is a natural adaptation for multistory concrete structures wherein the floor system is framed with girders or beams, since the joints between the beams and columns inherently tend to be continuous.

2. LAYOUT OF FRAMING. Spacing shall be in consonance with economical spans for subframing, as previously discussed. The following procedures are recommended:

(1) Repeat all beams and construction details from floor to floor for maximum reuse of forms.

(2) Increase the reinforcing, wherever possible, instead of changing concrete dimensions.

(3) To facilitate reuse of forms, make roof constructions the same as floor construction.

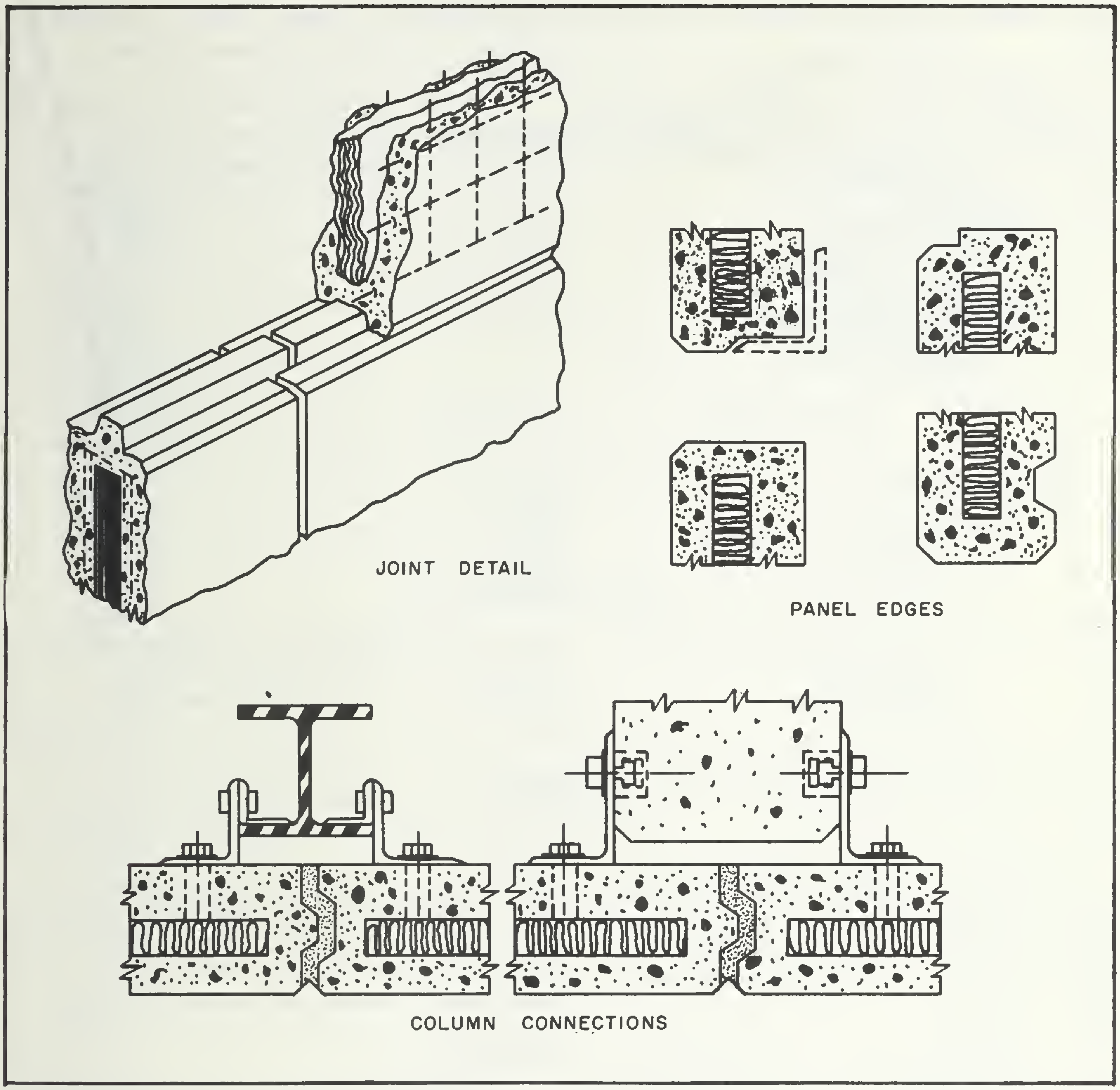


FIGURE 9-28
Precast Concrete Wall Details

Part 4. CONCRETE FOUNDATION STRUCTURES

1. FOOTINGS. In general, use square or rectangular footings, reinforced in both directions. Where space is restricted or conditions are such that isolated footings are not feasible, use combined rectangular, trapezoidal, or cantilever footings. Footings and reinforcements shall be designed in accordance with Chapter 3 and Figure 9-35.

2. MATS. Where low values of soil bearing capacity require that a large portion of the building area be utilized for footings, and where economically competitive with a pile supported design, consider the use of a mat. Design procedures and assumptions found in *Soil Mechanics, Foundations and Earth Structures,* NAVFAC DM-7, apply.

a. Rigidity. To increase rigidity, beams can be used. Beams shall be cast integrally with the

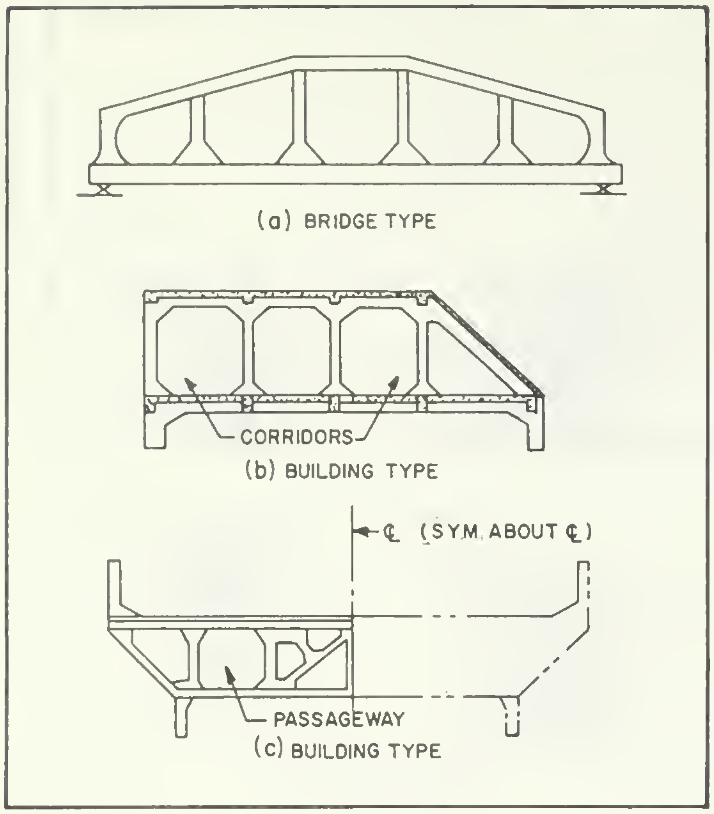


FIGURE 9-29
Concrete Trusses

slab. Sometimes these beams are open frames running upward a full story or more.

b. Uplift. Mats constructed below water level must be checked for hydrostatic uplift, which may not affect a design as a whole, but which requires special details for watertightness and strength of side wall connections. An underdrainage system usually is desirable.

3. RETAINING WALLS.

a. Loads. Earth pressure loads applicable to retaining walls are contained in *Soil Mechanics, Foundations, and Earth Structures*, NAVFAC DM-7.

b. Types and Uses. Types and uses of retaining walls are found in Table 9-4 and Figure 9-36.

c. Drainage. Drain all walls as described below, unless specifically designed for hydrostatic pressures in combination with earth loads.

(1) Weep Holes. Provide weep holes 4 inches in diameter, 6 inches above lower grade at the exposed face of walls spaced not more than 15 feet on centers. At least one weep hole should be provided in each panel of counterfort walls.

(2) Backwall Drainage Systems.

(a) Horizontal pockets. Provide continuous horizontal pockets of broken stone or gravel, with a 2-square-foot cross section against the wall pressure faces. The bottom of a pocket should be at the level of weep hole inverts and should connect to them. Horizontal pockets should extend full lengths of the panels between counterforts, and should be connected with adjoining horizontal pockets by sleeves through the counterforts.

(b) Vertical chimneys. Provide vertical chimneys of broken stone or gravel, with a 2-square-foot cross section, spaced not over 15 feet on centers. Chimneys shall contact wall pressure faces and should extend from tops of horizontal pockets of broken stone or gravel to within 1 foot of finished grades. At least one vertical chimney should be included in each panel of counterfort walls.

(c) Protection. Protection against infiltration of earth into the broken stone or gravel of horizontal pockets and vertical chimneys is necessary. Use fiber reinforced paper or an inverted filter drain.

d. Vertical Joints. Space the required vertical joints in accordance with Chapter 3.

(1) Alignment. Joints in one portion of a wall should line up with and form a continuation of joints in other portions of the wall or building.

(2) Control Joints. Control joints as shown in Figure 9-37 are for use in cantilever walls without conterforts or buttresses. The joints should be modified as necessary to resist bending stresses in walls with counterforts or buttresses.

(3) Expansion Joints. Provide expansion joints at ends of retaining walls which would be otherwise restrained by a structure.

e. Horizontal Joints. Avoid the use of horizontal construction joints at points other than junctions between vertical walls, counterforts or buttresses, and the base of the wall. Horizontal joints should be keyed and doweled to transmit induced shears and bending moments. Locate a key at the center of a vertical wall in a depression in the base slab to avoid interference with vertical bars or dowels. However, in L-shaped walls, where the base projects on the exposed face side of the wall, a key may be necessary, extending from the center of the wall to pressure face to develop shear.

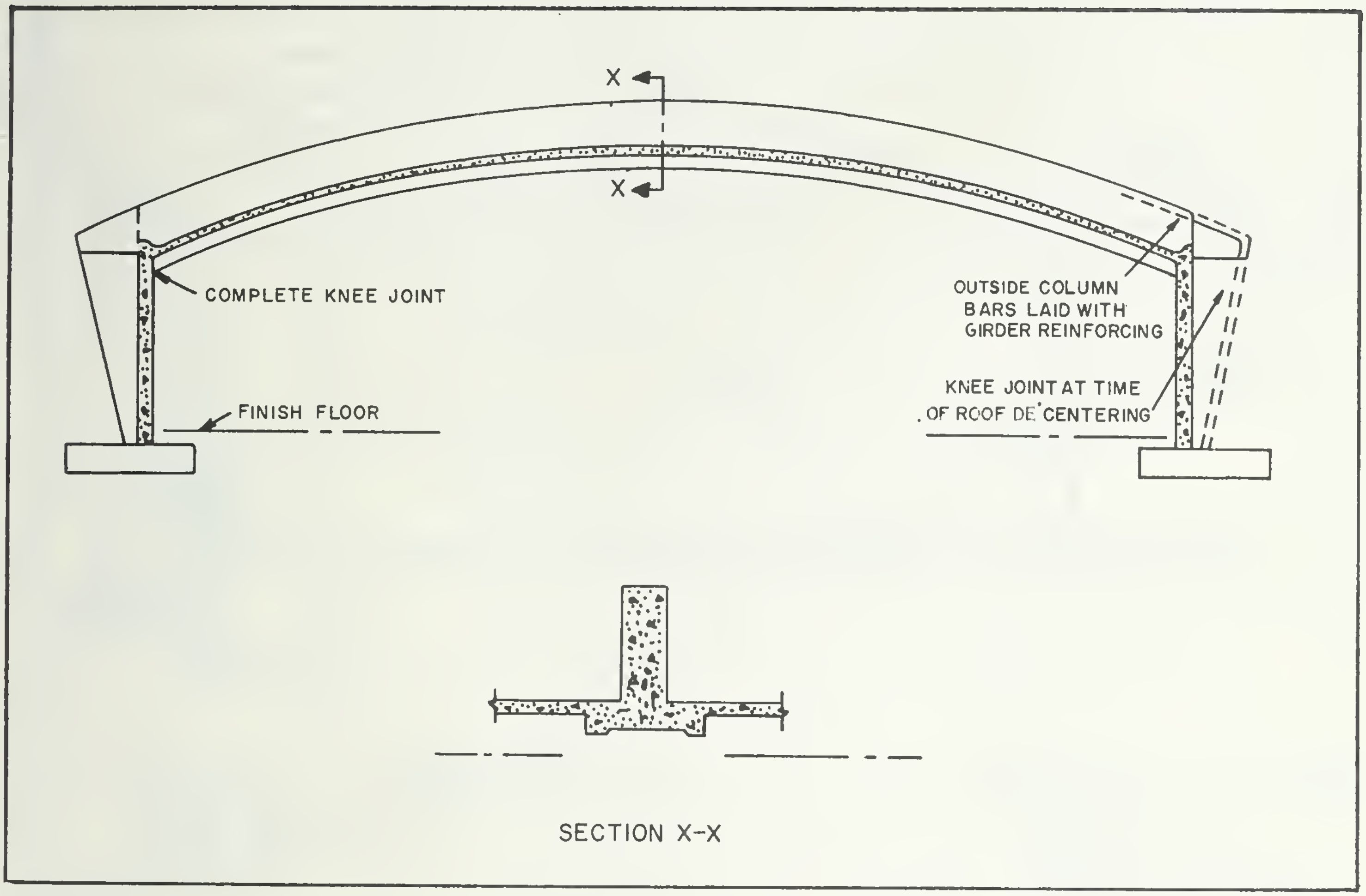


FIGURE 9-30
Rigid Frame Bent

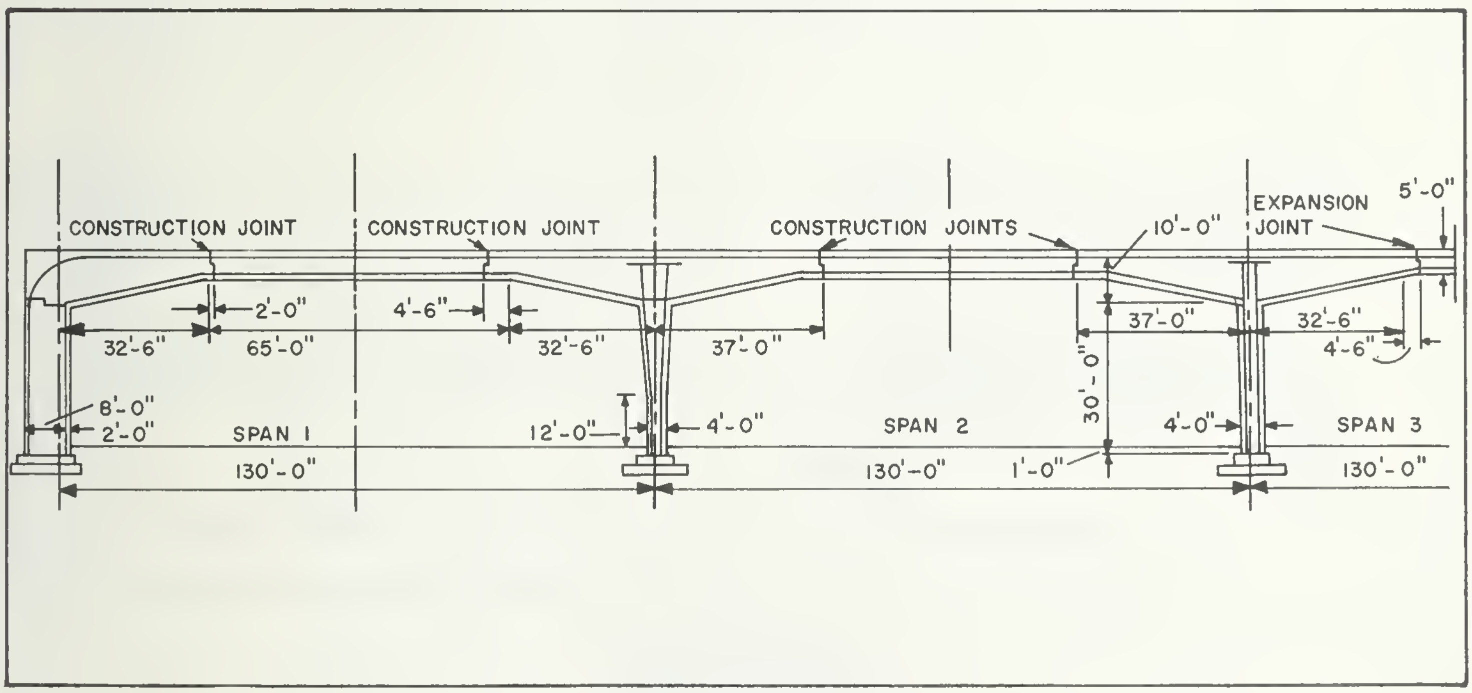


FIGURE 9-31
Rigid Frame Construction Flight Hangar

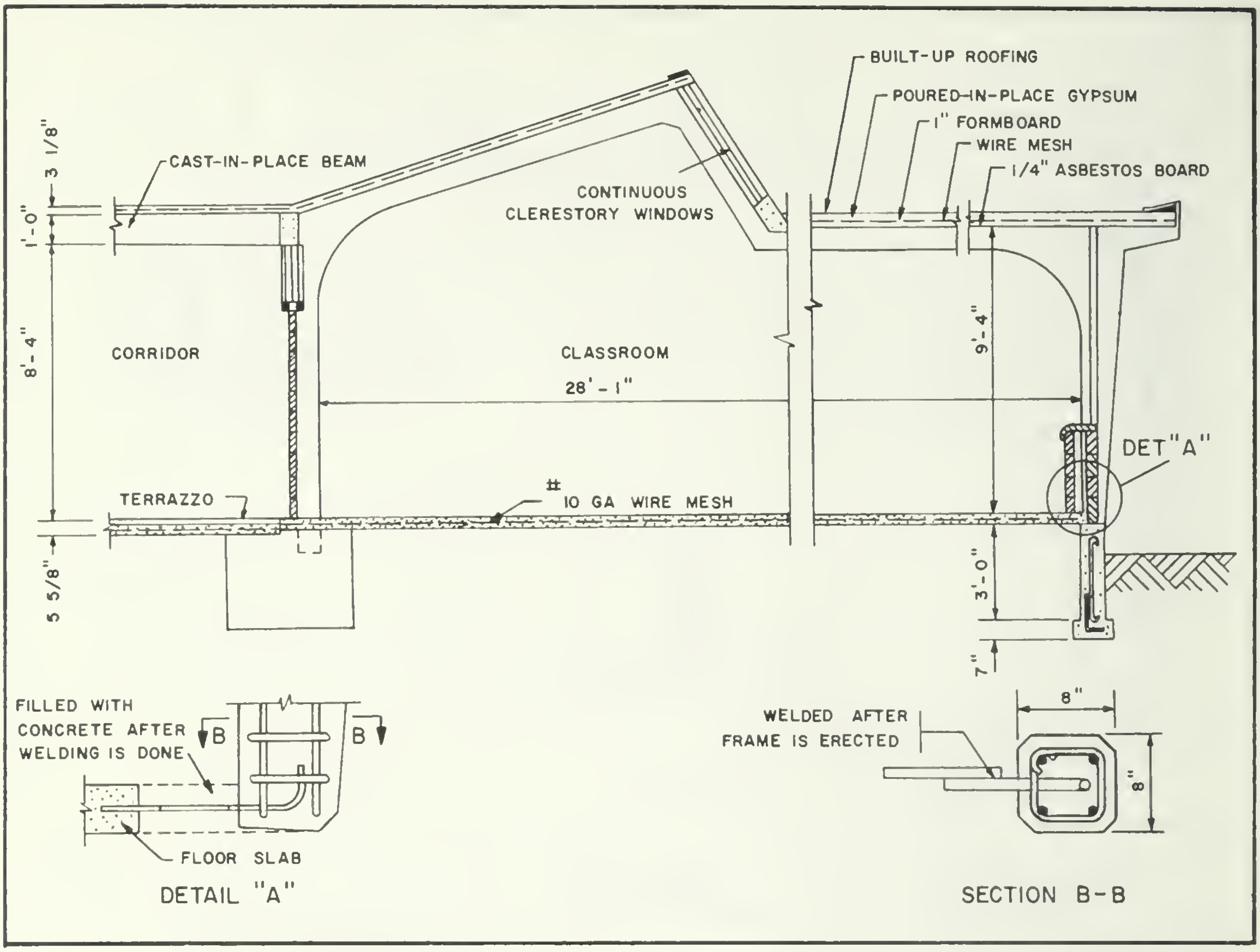


FIGURE 9-32
Rigid Frame Bent

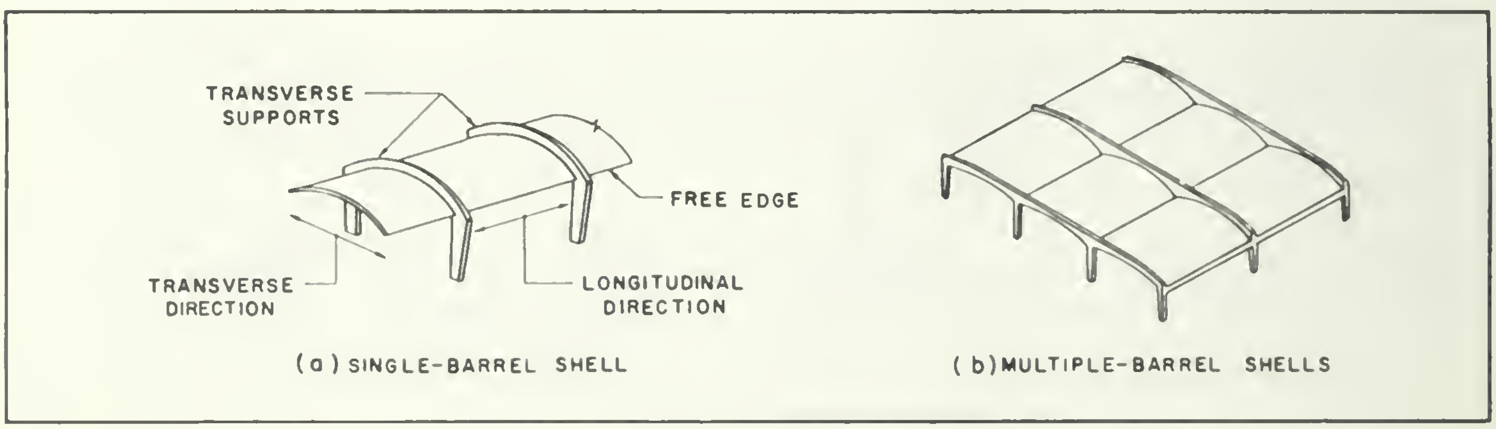


FIGURE 9-33
Barrel-Shell Roofs

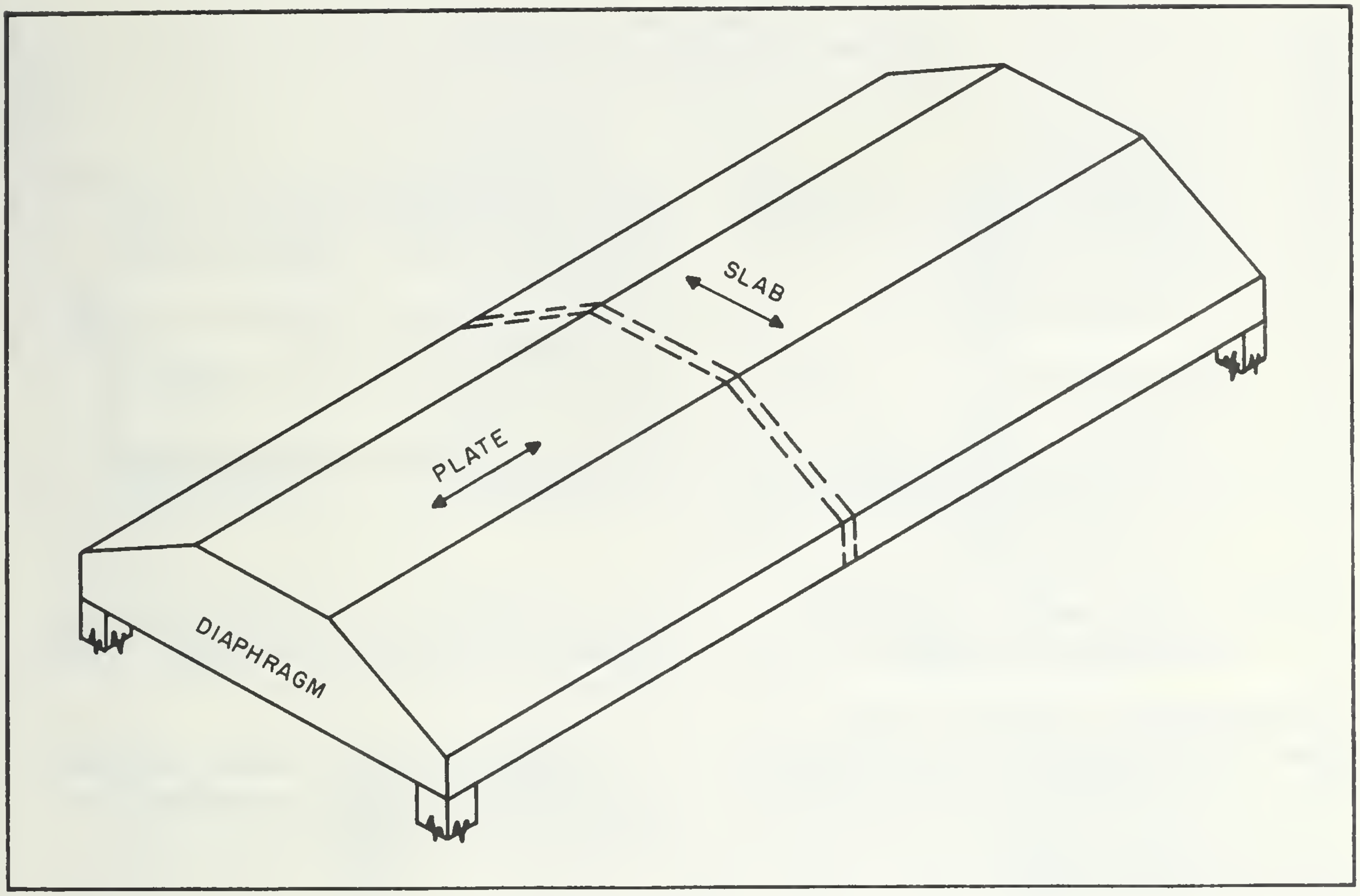


FIGURE 9-34
Folded-Plate Roof

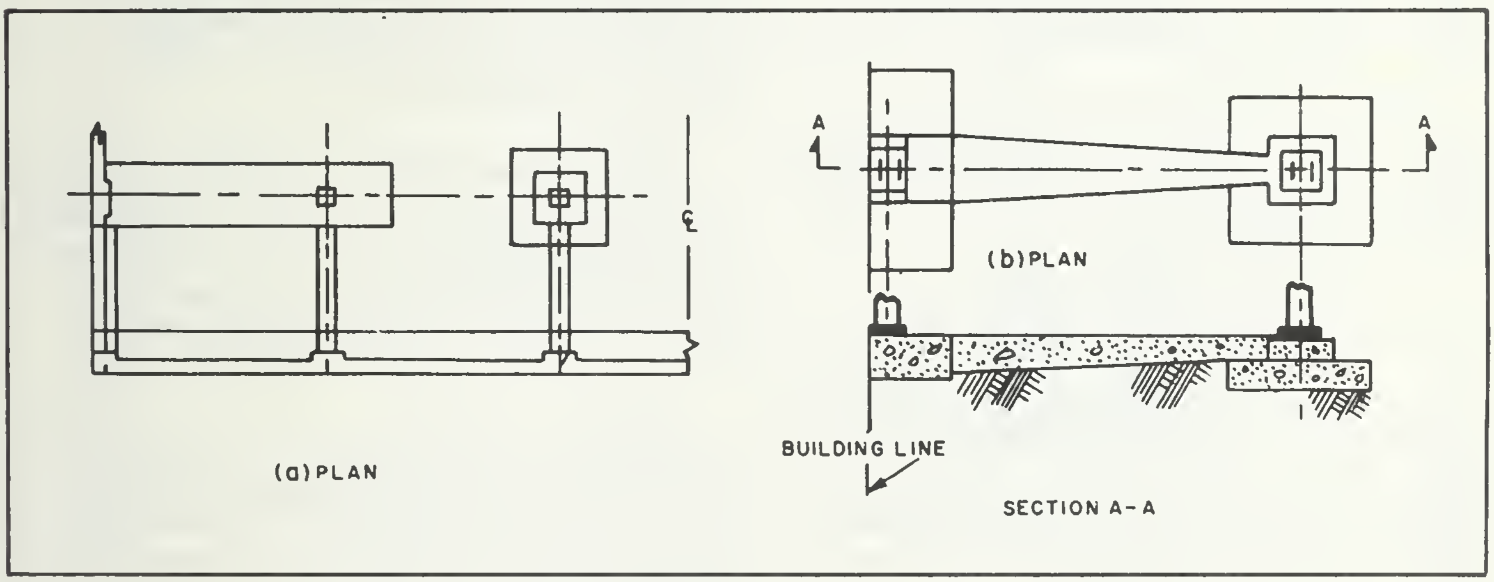


FIGURE 9-35
Combined Footings

TABLE 9-4
Selection Factors for Retaining Walls

Type No.	General type	Typical use
1	Gravity walls	Lack of skilled labor for other types.
2a	Cantilever Tee walls	Use unless restricted by property lines.
2b	Cantilever Ell walls	Use of property lines when adjoining grades below site grades.
2c	Cantilever Ell walls	Use at property lines when adjoining grades are higher than site grades.
3	Terrace walls	Maximum difference in grade, 3 ft; no surcharge in excess of 50 psf.
4	Crib walls	Eliminates formwork.
	Counterfort or buttressed walls	Very high wall and/or subject to unusually heavy lateral pressure.

Part 5. CONCRETE TANKS AND STORAGE FACILITIES

1. CONVENTIONAL CONCRETE TANKS. Conventional concrete tanks include circular shapes and rectangular, octagonal, and other odd shapes.

a. Circular Tanks. Concrete tanks with circular cross sections should be used for storage, only if prestressed.

b. Odd Shape Tanks. Rectangular, octagonal, and other odd-shaped tanks and reservoirs with straight sides can be made of poured-in-place concrete. These tanks should be designed to resist both internal and external pressures by bending strengths of component parts.

c. Walls. The following criteria shall be considered when designing walls for odd shape tanks or storage containers. Typical wall designs are listed in *Liquid Fueling and Dispensing Facilities*, NAVFAC DM-22.

(1) Counterforts. Counterforts may be economical for high walls of rectangular tanks.

(2) Corner Expansion. If there are no corner expansion joints, design for horizontal bending stresses. Fillets should be provided at corner locations. For sidewalls cast monolithically with bases, provide for bending stresses at junctions of sidewalls and bases as well as at corners, as described in Chapter 3.

2. LARGE TANKS. Walls of large tanks or reservoirs that are other than circular should be designed as retaining walls with independent footings. Large reservoirs should have one or more internal division walls to allow cleaning or repairing without disrupting reservoir operation. Provide the means of support as follows.

a. Flat Slabs. Floors of large, earth foundation reservoirs with column supported roofs may be flat slabs on the ground.

b. Concrete. If excavation is in rock, cover the rock surface with sufficient concrete to provide a smooth surface to facilitate cleaning.

c. Footings, Sill Blocks. Columns may be supported on individual footings and floor slabs may be supported on concrete sill blocks. Slab thicknesses reinforced with light welded wire fabric may vary from 4 to 6 inches in depth, depending on the tank height.

3. SMALL TANKS. Bases for small tanks should be designed as slabs, fixed at the peripheries, and uniformly loaded. If floors are laid as slabs (fixed at supports) connections with the sidewalls are rigid, and no special provisions are needed for expansion, contraction, or settling.

4. ROOFING. Roofs usually are required when tanks and reservoirs are employed for storing water. Contamination, formation of objectionable growths, freezing, evaporation, and undesirable heating conditions are prevented by the use of roofs.

a. Small Tank Roofs. Roofs of small tanks should be the slab and girder type, spanning from wall to wall.

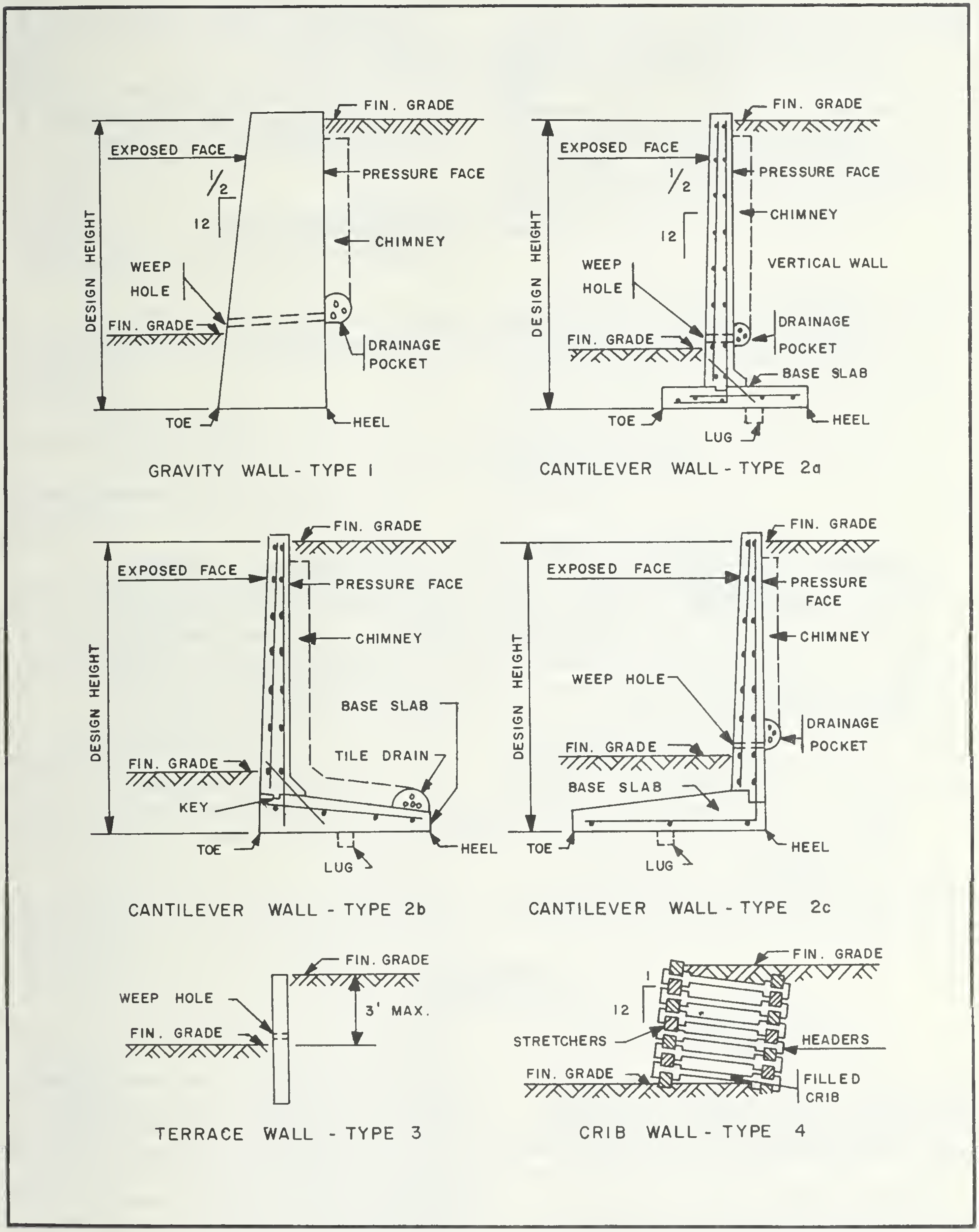


FIGURE 9-36
Retaining Walls

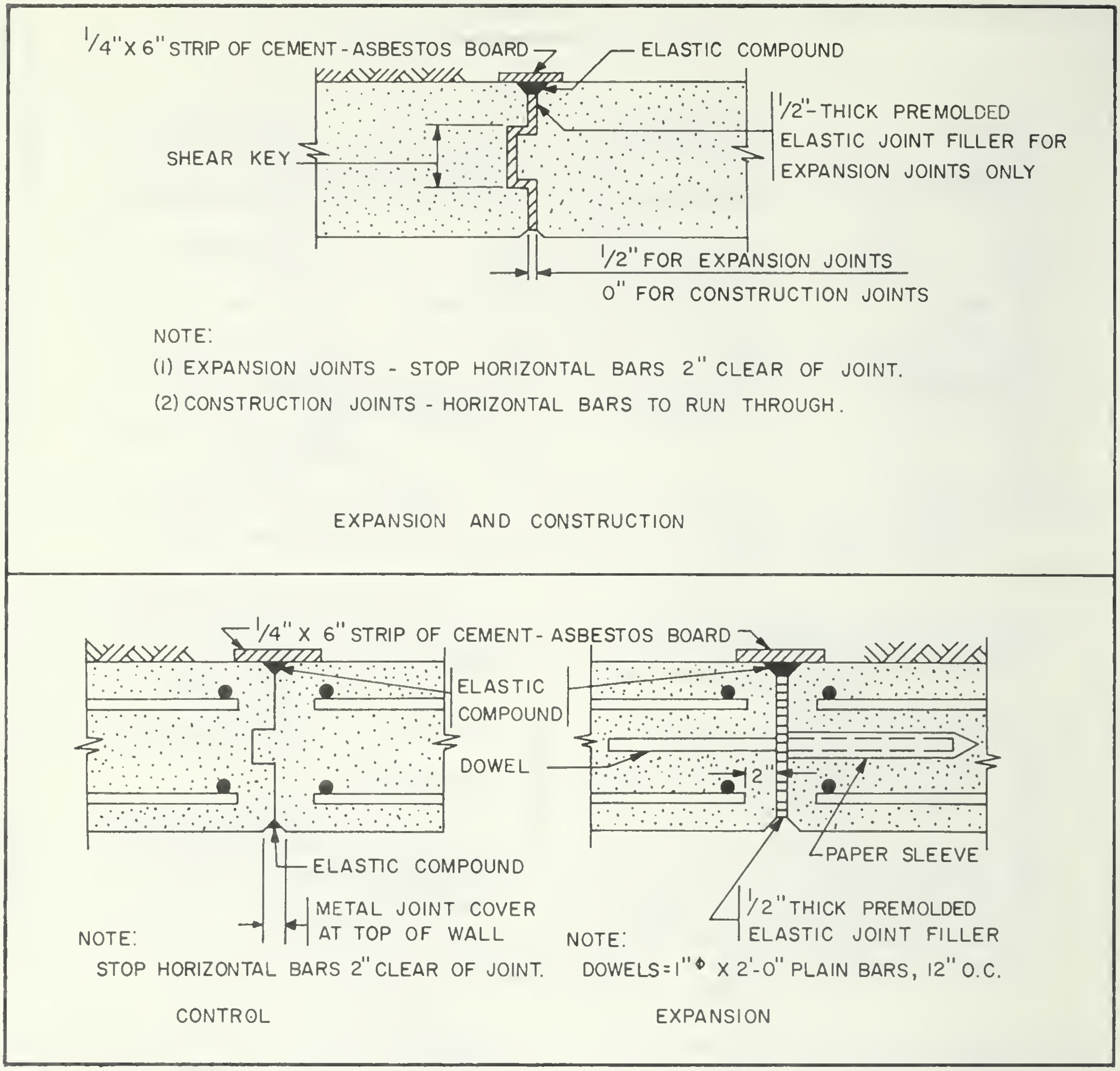


FIGURE 9-37
Retaining Wall Joints

b. **Large Tank Roofs.** The flat slab type of roof, carried on columns, should be used for large tanks. Roofs subject to temperature changes should rest on the walls for a sliding joint.

5. **UNDERDRAINAGE**. Where bottoms of tank slabs are below ground water level, the empty tank shall be heavy enough to prevent floating, and floors shall be designed for full hydrostatic uplift with the tank empty and ground water at maximum elevation, unless a special underdrain and pump system are provided. Where tank floors overhang the sidewalls, the weight of earth overlying the overhang and bounded by vertical planes at the limit of the overhang may be considered as resisting the tendency of the tank to float. Where tanks are compartmented, the weight of the tank, with only one compartment full, shall be adequate to resist buoyant forces resulting from a hydrostatic uplift on the entire base equal to the full pressure head in the tank. Design the floor slabs to resist this pressure head.

6. PRESTRESSED CONCRETE TANKS. To avoid tensile stresses in the concrete sidewalls, storage tanks of circular cross section should be prestressed with the following materials:

Type of prestressing	*Minimum yield stress (psi)*
Steel rods	40,000
Alloy steel rods	135,000
Cold drawn wire	175,000

a. Walls. The design of walls for prestressed concrete tanks requires provision for stress factors, both in the selection of materials and in their application.

(1) *Assumed Factors.* Assume stress analysis factors for a typical installation.

(a) *Wall condition.* Tank walls are free at the top, and are halfway between free-sliding (with no angular rotation) and fixed at the base.

(b) *Rods and wire.* To allow for shrinkage, plastic flow, and mechanical loss of prestressing, assume that working stresses of the steel rods and cold drawn wire (see preceding list, used for prestressing are 85 percent of initial prestress.

(c) *Residual compression.* Calculate the residual compression stresses for concrete, resulting from combined vertical bending and ring stresses, as being no less than 50 psi; for tanks prestressed by steel rods, calculate the residual compressive concrete stresses for ring forces as not less than 25 psi.

(2) *Installation.* Vertical and circumferential stresses may be controlled by proper placement of reinforcement. Areas of gunite cover and bands of reinforcement shall be included when computing the moment of inertia of the wall section.

(a) *Vertical bending moments.* To resist vertical bending moments, place reinforcing steel vertically in the walls and use alloy steel rods and cold drawn wire for vertical prestressing. Place steel used for vertical prestressing at the center of tank wall forms; complete such installation before starting circumferential prestressing.

(b) *Circumferential prestressing.* Circumferential prestressing is accomplished by using turnbuckles to shorten the externally placed rods. Provide staggered wall recesses to allow for tightening of turnbuckles. Rods should be not larger than $1\frac{1}{8}$ inches in diameter and not longer than 35 feet, with initial prestresses not exceeding 27,500 psi. Apply initial prestressing in bars with a torque lever. Include in designs the lever length and load to be applied to develop initial prestresses in various bar sizes. For alloy steel rods and cold drawn wire, place circumferential prestressing steel either on exterior surfaces or near the centers of tank walls and tighten by use of special anchorages and jacks, or by a special machine that winds wire spirally on the tank exteriors.

b. Wall Joint. Joints recommended for use at prestressed tank wall bases are shown in Figure 9-38. Protect prestressing steel in tank walls by tubes or bond-preventing coatings. If a tube is used, fill it with cement grout after prestressing. For tanks with exterior prestressing steel, place a protective layer of cement grout or pneumatic mortar at least $\frac{3}{4}$-inch thick over the steel after prestressing.

c. Roofs. If tank roofs are supported by columns, both floors and roofs shall be designed as flat slabs. Concrete dome roofs may be used. These domes shall be spherical, with rises designed for uniform dead and live loads. Provide prestressed ring girders at junctions of domes and tank walls to resist dome ring and tangential stresses. Because of discontinuities of domes at rings, shells shall be thicker there and reinforced to resist bending and shear in meridian directions. Prestress ring girders, allowing no tensions in the girder concrete under full live and dead loads.

d. Typical Designs. Standard plans for prestressed concrete tanks are listed in *Liquid Fueling and Dispensing Facilities*, NAVFAC DM-22.

Part 6. CONCRETE BUOYANT FOUNDATIONS

1. CONDITIONS FOR USE. The use of buoyant foundations should be considered under the conditions cited:

a. Low Capacity Supporting Soil. Where the capacity of the supporting soil is low, buoyancy can be utilized to reduce the contact pressure between structure and supporting soil. Pressure reduction shall not exceed 75 percent of dead load.

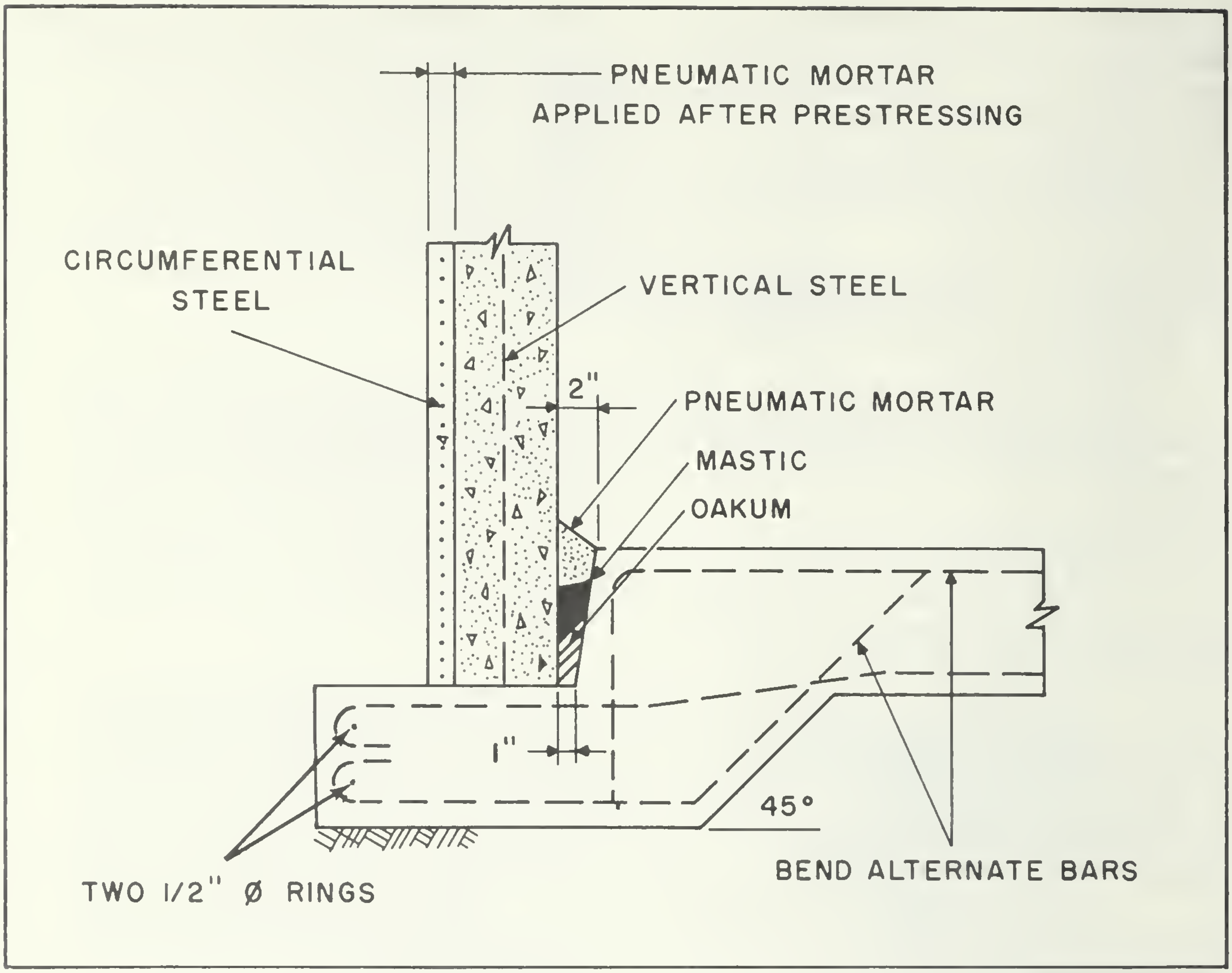


FIGURE 9-38
Joint at Base of Tank Wall for Prestressed Concrete Tank

b. Additional Storage Space. Additional storage space is not a prime reason for choosing buoyant foundations; however, it is an added consideration.

c. Restrictions. Do not use buoyant foundations where swift currents or severe wave actions can undermine the foundations. Take extraordinary precautions to insure complete watertightness and sound construction, at all construction joints, especially when exposed to high tidal variations.

Part 7. CONCRETE TOWERS

1. **CONCRETE TOWERS.** The use of concrete for the construction of towers depends on the availability of structural steel. In corrosive environments, concrete shall be used for short towers. The use of concrete for tall towers is uneconomical, however, and thus concrete should be utilized only if structural steel is unavailable and after effort has been made to reduce the dead load and presentment to wind.

2. **FRAMING DETAILS.** For tank supports framing details, lay out beams for tank floors depending on tank sizes and on spacings of tower columns in each direction. Towers should be square shaped. Figure 9-39 shows the major floor areas of a tower to be covered by a tank. Provide for greatest economy by using two floor beams in each direction to frame with girders at third points. Floor beams with the same section and the same span each carry one-fourth the tank loads regardless of beam intersections at third points of panels. Design

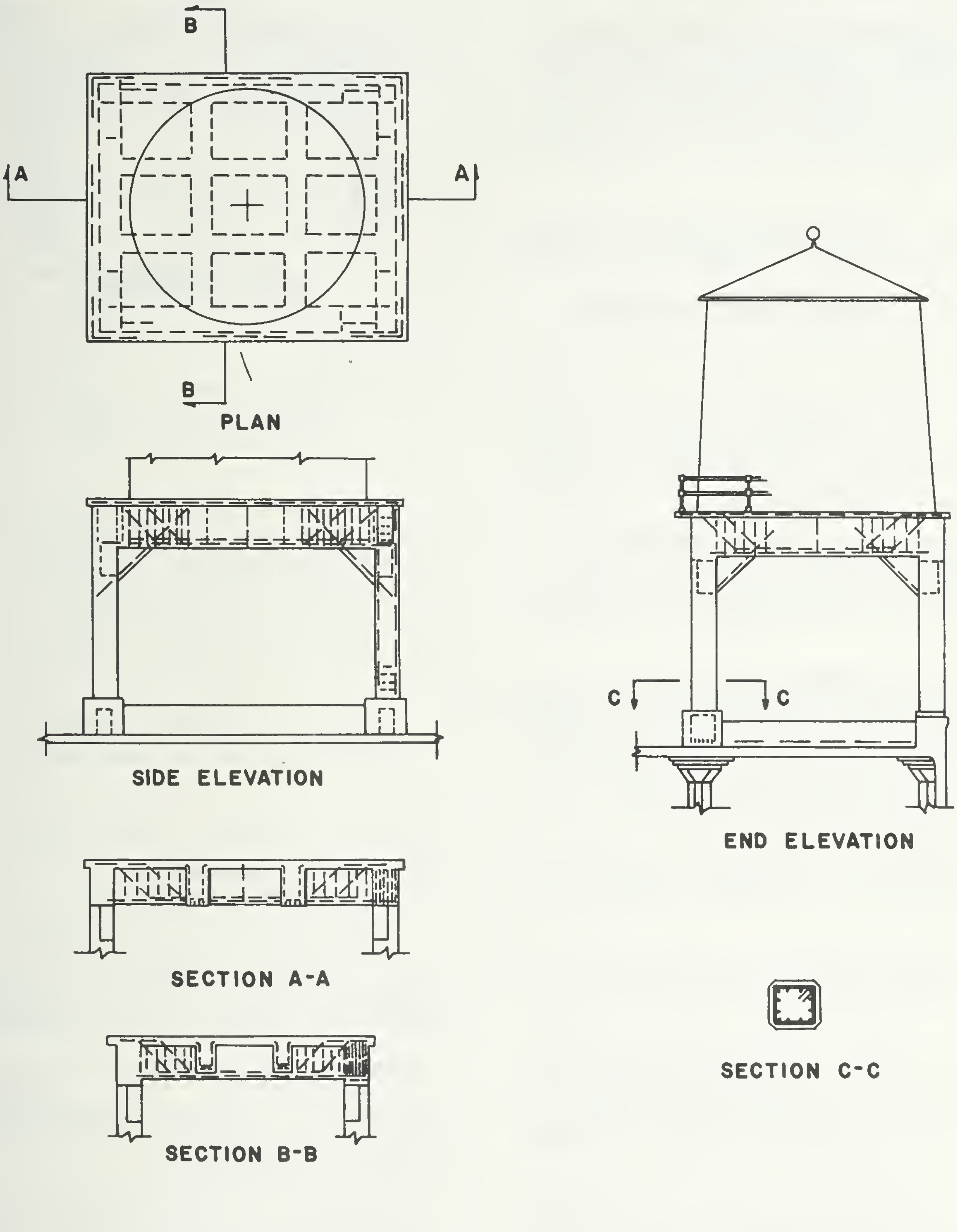


FIGURE 9-39
Typical Framed Tower of Reinforced Concrete

floor beams as T-beams and design girders as rectangular beams. Use intermediate floors or diaphragms in high towers (Figure 9-40).

3. BOMB-RESISTANT AND BLAST-RESISTANT STRUCTURES. Obtain the latest criteria for bomb-resistant and blast-resistant concrete structures from the Naval Facilities Engineering Command. For collateral reading on the subject, see the Bibliography in this publication.

Section 5. TIMBER STRUCTURAL SYSTEMS

Part 1. OVERALL REQUIREMENTS

1. LIMITATION. The following criteria shall be used for all structural timber construction other than family housing. Requirements for family housing shall conform to the criteria given in *Family Housing*, NAVFAC DM-35.

2. ALLOWABLE STRESSES AND DESIGN STANDARDS. Allowable stresses and design standards for timber construction are contained in Chapter 4.

3. TYPE OF CONSTRUCTION. The type of framing selected for wood framed buildings, or similar structures, should be based on requirements for proper selection of structural elements and on the general provisions stated in this section.

4. SHRINKAGE. Wood framed buildings shall be designed with regard to the effect of normal wood shrinkage.

a. **Specifications.** Structural lumber shall be specified as seasoned lumber with a moisture content not exceeding 20 percent. When seasoned lumber is unavailable, unseasoned lumber may be used, but framing requirements shall be governed by the recommended practices to reduce vertical shrinkage, as given in the *Wood Handbook*, USDA. (See Criteria Sources.)

b. **Fabricated Lumber.** If structural lumber is fabricated before seasoning and is used in a dry location, the exposed end grains shall be sealed while the lumber is wet.

5. BRIDGING. Wood cross bridging measuring $1\frac{1}{4}$ by 3 inches (nominal) shall be nailed between joists and rafters, at maximum intervals of 8 feet. Solid blocking should be placed between joists at points of support where it will be effective as a firestop.

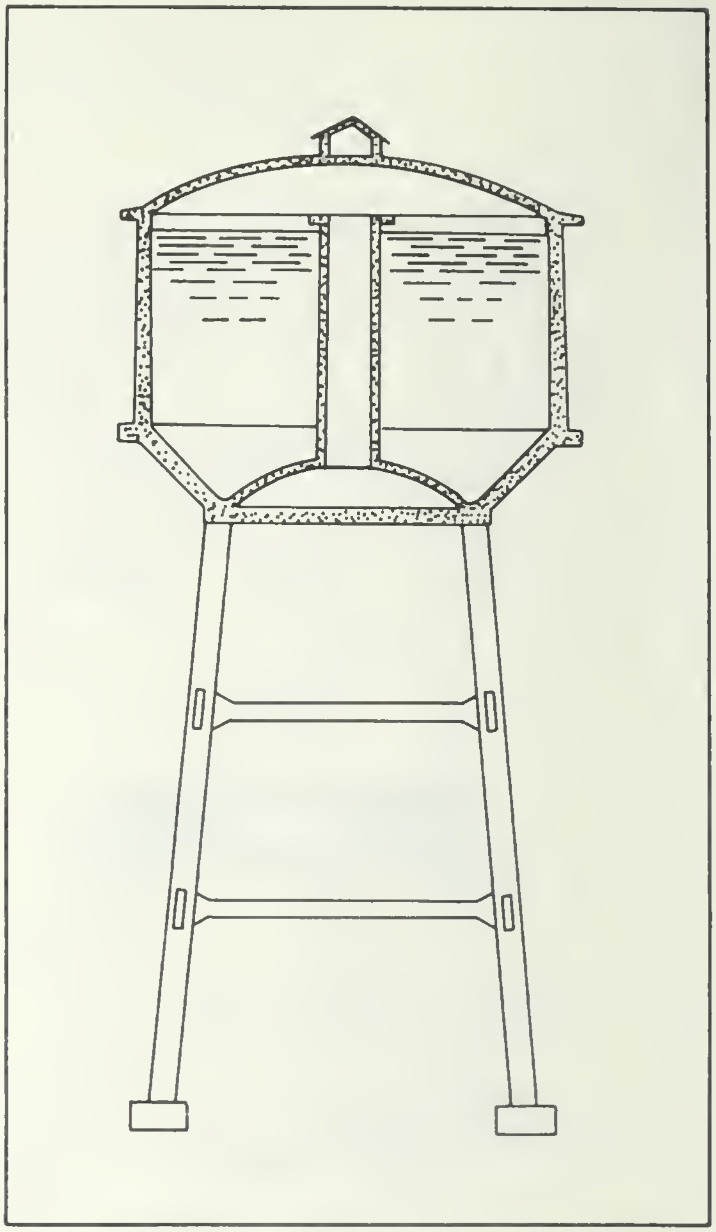


FIGURE 9-40
Elevated Water Reservoir

6. BRACING. Where wood trusses or trussed rafters are used in roof construction, they shall be securely stayed by diagonal and sway bracing against any lateral forces.

7. SHEATHING. For all wood framed buildings, wood sheathing (other than paneled sheathing) on the exterior walls and subflooring should be laid diagonally. Roof sheathing may be laid perpendicular to supports, except where diagonal sheathing is required for additional rigidity. Additional criteria are contained in *Architecture*, NAVDOCKS DM-1.

8. **HEADERS AND TRIMMERS.** Double all headers over 4 feet long, and double trimmer joists which support double headers.

9. **CHIMNEYS.** Do not place wood framing closer than 2 inches to a chimney. See *National Building Code*, American Insurance Association, for detailed clearance requirements. (see Criteria Sources.)

10. **NOTCHING.** Structural members shall not be notched or bored for pipes, ducts, or other purposes except as provided by design standards.

11. **HORIZONTAL MEMBERS.**

a. **Joists.** Joists that are under and parallel to bearing partitions shall be doubled and securely spliced or separated by solid blocking spaced not more than 16 inches on centers to permit the passage of pipes, ducts, or other conduits.

b. **End Bearings.** End bearings on masonry walls should be at least 4 inches for joists and 6 inches for beams. Joist and rafter ends built into masonry walls shall be cut to a bevel, the bevel top extending into the wall not more than 1 inch. Extreme ends of joists and rafters shall be not less than 4 inches from the far face of walls.

12. **WALL ANCHORS AND TIES.** The minimum anchorage requirements for buildings having wood framing are as follows.

a. **Foundation Walls.** Wood framing that rests on masonry or concrete foundations shall be secured to a continuous wood wall plate not less than 2 by 6 inches. The plate is secured by metal anchors having a minimum dimension of 5/8 inch round. When masonry is used, anchors shall be 2 feet long; when concrete is used, anchors shall be 1 foot long. Anchors shall be spaced a maximum of 4 feet on centers. In general, sills should be 4 by 6 inches.

b. **Masonry Walls.** Wood framing that bears on masonry walls shall be anchored to the walls by metal anchors, placed near the bottom of joists, and spaced not over 4 feet apart.

(1) Spacing. In joists that are parallel to the wall, space metal anchors no less than 6 feet apart, so as to engage three joists.

(2) Size. Metal anchors shall have a minimum cross section of $1\frac{1}{4}$ by $\frac{1}{4}$ inches. They shall be securely fastened to the joist and firmly embedded in the masonry wall.

c. **Beams or Partitions.** Ends of joists bearing on beams or partitions should be lapped and securely spiked. When joists are butted, they shall be connected together with metal straps or wood ties.

d. **Masonry Piers.** Wood beams or columns bearing on masonry piers shall have metal strap anchors not less than $1\frac{1}{4}$ by $\frac{1}{4}$ inches, into the pier not less than 2 feet, and securely fastened to the beams or columns.

e. **Column Connections.** All joists, beams, and girders at columns and other support points shall be connected together to form a continuous tie across the building. This tie shall be sufficient to resist wind loads applied outwardly to walls. All roof framing shall be anchored to resist wind suction.

13. **METAL SUPPORTS.** Headers over 4 feet long, tail joists over 10 feet long, and heavy timbers (without a direct bearing support) shall be carried on metal hangers. All wood beams bearing on wood columns should be supported on metal post caps in preference to wood bolsters. Fastenings shall be such that they will resist wind force uplift and provide a continuous tie across the joint.

14. **VENTILATION UNDER FRAMED FLOORS.** For wood framed floors over unexcavated spaces or unfinished spaces, provide an 18-inch (minimum) clearance aboveground to the nearest wood member (except 24 inches for tropical-humid climates). See *Architecture*, NAVDOCKS DM-1, for additional criteria. Provide a sufficient number of ventilating openings through the foundation walls and exterior walls to insure cross ventilation. Proportion these openings on the basis of a net area of 2 square feet for each 25 linear feet of wall space. Such openings should not be placed in the front wall of the buildings.

15. **DIAPHRAGMS.** Wood floors and roofs, when properly designed for the acting forces, can be used as diaphragms to distribute horizontal forces to resisting vertical elements of buildings.

16. **DEFLECTION.** Proportion floor joists and beams supporting plaster ceilings so that vertical deflections under full live load shall not exceed 1/360 of the span.

17. **FIRESTOPS.** Firestopping shall be provided to cut off all concealed draft openings, both horizontal and vertical, and to form an effective fire

barrier between stories and between a top story and a roof space.

a. Thickness. When firestops are of wood, they shall have a minimum nominal thickness of 2 inches. If the width of the opening is such that more than one piece of lumber is necessary, there shall be two thicknesses of 1-inch material with joints broken.

b. Application. Use firestops in the following locations.

(1) Floors and Ceilings. Provide firestops in exterior or interior stud walls, at ceilings, and at floor levels.

(2) Stud Walls and Partitions. Use firestops in all stud walls and partitions, including furred spaces. Place firestops so that the maximum dimension of any concealed space is not over 7 feet. In addition, provide firestops in furred masonry walls.

(3) Stairs. Provide firestops between stair stringers, at least one in the middle portion of each run at top and bottom. Also provide firestops between studs, along and in line with run of stair adjoining such partition.

(4) Sliding Doors. Use firestops around top, bottom, sides, and ends of sliding door pockets.

(5) Chimneys. Provide firestops for chimneys. The spaces between chimneys and wood framing shall be solidly filled with mortar, loose cinders, or other incombustible material placed in incombustible supports.

(6) Miscellaneous Areas. Use firestops in other locations, such as holes for pipes and shafting, which would allow passage for flames.

18. BEARING WALLS AND PARTITIONS. Wood stud bearing walls and partitions shall be designed to support vertical loads without assistance from sheathing or other covering.

a. Placement. Studs may be placed with the shortest or longest dimensions parallel with the wall or partition, if the studs in either case are considered as a column and designed to comply with the requirements of the column formulas.

b. Other Provisions.

(1) Top Plate. Top plates shall be doubled and lapped at each intersection with walls or partitions. Stagger joints in the upper and lower members of top plates not less than 4 feet.

(2) Bridging. Provide all stud partitions with bridging at midheight of studs, or by other means for giving equal lateral support to the studs. Bridging size shall be 2 inches by depth of stud.

(3) Corners. Angles at corners, where stud walls or partitions intersect, shall be framed to form a solid post. Thoroughly brace all exterior or cross-stud partitions.

(4) Openings. Provide all openings in stud walls, 4 feet wide or less, with double headers. These headers shall be not less than 2 inches thick, placed on edge, securely fastened together, and have 2 inches of solid bearing at each end extending to the floor or bottom plates.

(a) All openings over 4 feet wide shall be trussed or provided with lintels, which shall have not less than 2 inches of solid bearing at each end, to the floor or bottom plate.

(b) Use double studding around all openings.

(5) Concentrated Loads. Support all concentrated loads, such as floor or roof beams and girders, hip and valley rafters, and framing on stud walls, by adequate posts. Confine such posts to the thickness of the stud wall or partition, if possible.

(6) Chimney Clearance. Place all stud partitions at least 4 inches from the back of a fireplace or a chimney. See *National Building Code*, American Insurance Association, for detailed clearance requirements (see Criteria Sources).

(7) Underpinning. Construct bearing stud wall or partition underpinning to support the proper design forces.

19. WOOD COLUMNS. Frame all wood columns to true end bearing and extend down to supports that will anchor the columns securely in position. Protect the column bases from deterioration in accordance with the following provisions.

a. Basements. Provide basement supports extending a minimum of 4 inches above the finished floor line.

b. Metal Bases. If metal-column bases are used, they shall be securely fastened to the column and anchored to the supporting footings or piers.

c. Direct Splicing. Wood columns should not rest on wood floor beams, except in cases where there are no columns below.

d. **Ends.** Ends of wood columns shall be treated with a preservative if protection against dampness is necessary.

e. **Exposure.** Wood columns should not be built into masonry partitions or walls in whole or in part.

20. **MAINTENANCE.** Specify that the nuts for all bolted members shall be retightened to a snug fit, between 12 and 18 months after a structure is completed.

Part 2. FLOORING

1. **SHEATHING.** Criteria for flooring sheathing is contained in *Architecture*, NAVDOCKS DM-1.

2. **PLANK.** Plank deck is tongued and grooved, or splined as shown in Figure 9-41. Individual pieces are to be nailed or bolted directly to the supporting members, and should be two bays in length whenever possible. In addition, they should be laid to break joints every 4 feet.

3. **LAMINATED.** For laminated decks, generally use planks 4 inches or more in width and 2 to 3 inches in thickness set on edge, side by side. Firmly nail the planks alternately at top and bottom at about 8-inch intervals with 20- or 30-penny nails (Figure 9-41). There are two methods used in laying laminated decks.

a. **Common Method.** The common method of lamination is to place every third piece from center to center of two girders. The piece next to this member is nailed with one end at the quarter point of the span between girders, and the other end extending three-fourths of the way across the adjacent span. The next piece is nailed with one end between the girders at the opposite quarter point.

b. **Random Length Method.** The use of random lengths requires more care in laying, and at least 50 percent of the pieces should pass over one or the other of the supports to the quarter point of the adjacent span. There should be not more than two splices at the same point in any 1-foot width of the span, and no splices in the middle third. Planks and laminated decks laid up as described can be designed conservatively as simple beams.

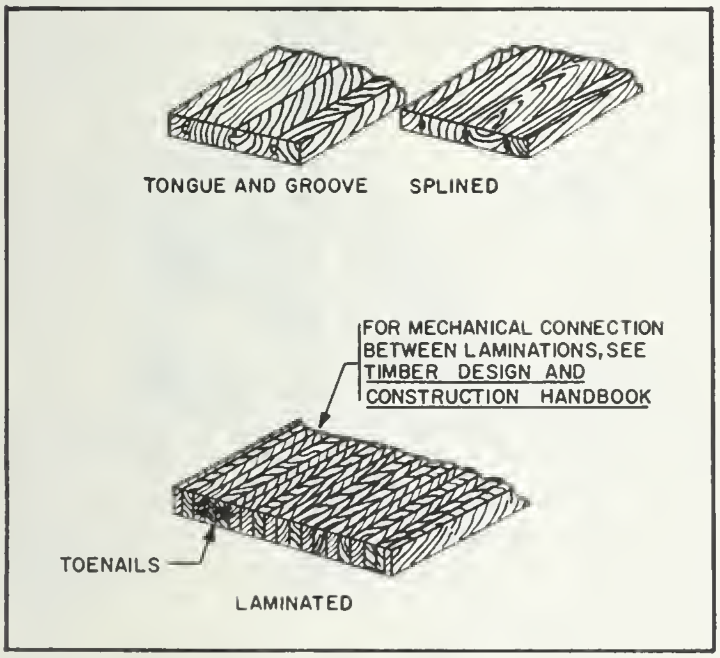


FIGURE 9-41
Types of Plank Decks

Part 3. BUILDINGS

1. **LIGHT FRAME CONSTRUCTION.** Use light frame construction for small buildings, residences, or structures with light loads. Light frame construction consists of three major types: braced, balloon, and platform.

a. **Braced Frame.** Braced frame construction employs corner posts and girts that are made of two or three pieces of 2-inch lumber to take the place of solid timbers. Firestops of 2-inch lumber, provided in accordance with criteria stated in *Fire Protection Engineering*, NAVDOCKS DM-8, are required to reduce the speed of initial involvement. Partition studs rest directly on the girder; this tends to eliminate settling due to unequal shrinkage in the walls and bearing partitions.

b. **Balloon Frame.** Balloon frames are built almost entirely of 2-inch lumber and nails. This type of framework is distinguished by wall studs extending up two stories high, with the ends of second floor joists spiked to their sides and resting on a false girt or ribbon boards. Continuous wall and corner studs make the structure very rigid (or stiff). Corner bracing adds to stiffness, but need not be used when the sheathing is applied diagonally. Elimination of girts in the walls requires fitting of

firestops between the studs to prevent the circulation of air throughout the walls. Floor headers and firestops between the joists decrease circulation. The balloon frame offers the advantages of speed and economy and possesses excellent rigidity.

c. Platform Frame. Platform frame construction consists of a first floor built on top of foundation walls though it were a platform. Wall and partition framing is run up another story to support another platform for the second floor. The third, or attic floor consists of another platform built on the second floor wall and partition framing, thus making the whole a series of platforms, each supported by independent partitions. The platform feature of this frame automatically firestops the walls and partitions at each floor level. Select the platform frame for the fastest and safest form of good construction. When braced with diagonal sheathing or let in bracing, it is rigid enough to withstand severe windstorms.

d. Plank and Beam Construction. Plank and beam construction may be used for the building types listed for light frame construction, and also for small factories and warehouses, particularly if they can be limited to one story.

(1) Construction. Floor and roof decks are constructed of 2-inch, or thicker, tongued and grooved or splined timber laid as directed in Part 2.

(2) Support. The floor and roof decks are carried on solid or built-up beams spaced on 4-foot, or greater, centers, each beam being supported individually by columns that are made of solid or built-up sections also.

(3) Fire Safety. The continuous floor and roof decking acts as a firestop.

(4) Simplicity. The elimination of a multiplicity of framing members affords speed of erection and simplicity of detail. It is possible to expose much of the structure and to omit finish flooring and ceiling treatment.

(5) Flexibility. The modular nature of the system is well adapted to the use of sheet- or panel-type materials.

(6) Insulation. More than ordinary consideration must be given to the choice of thermal insulation and to condensation control.

2. HEAVY TIMBER CONSTRUCTION. Heavy timber construction (termed mill construction) is used primarily for factories and warehouses. Interior structural elements, including columns, floors, and roof construction, consist of heavy timbers with smooth flat surfaces assembled to avoid thin sections, sharp projections, and concealed or inaccessible spaces. The three basic types of floor framing used in heavy timber construction are plank floor and beam framing; laminated floor and beam framing; and plank floor, beam, and girder framing. (See Figures 9-42, 9-43, and 9-44 for typical illustrations.) Also, floor beams (Figure 9-44) can frame into girders, using metal hangers, to reduce the construction depth.

a. Plank Floor and Beam Framing. Plank floor and beam framing (termed standard mill construction) consists of floors of heavy plank that are laid flat upon large girders. The girders are spaced from 8 to 12 feet on centers, and are supported by wood posts or columns spaced from 16 to 25 feet apart.

b. Laminated Floor and Beam Framing. Laminated floor and beam framing (termed mill construction with laminated floors) employs floors of heavy plank that are laid on edge and are supported by girders. The girders are spaced from 10 to 20 feet on centers, and are supported by wood posts or columns spaced 16 feet, or more, apart, depending on the design of the structure.

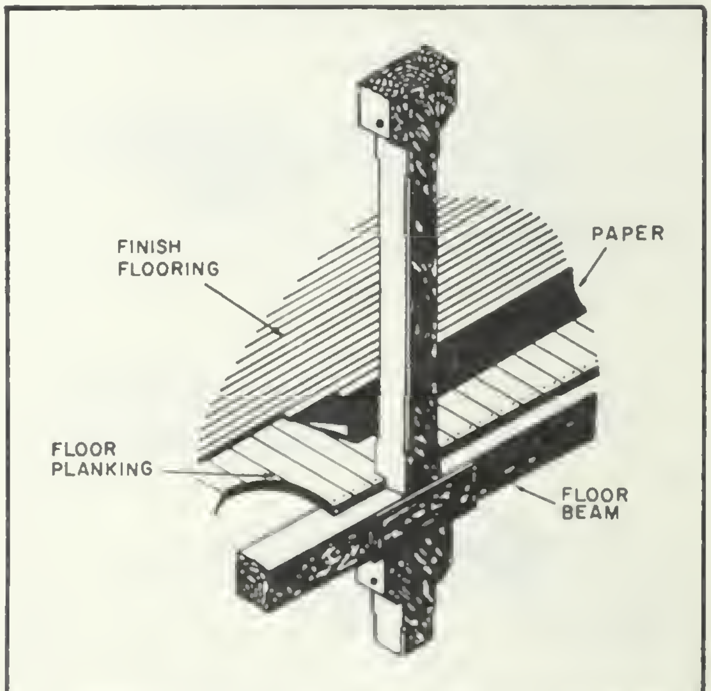


FIGURE 9-42
Plank Floor and Beam Framing

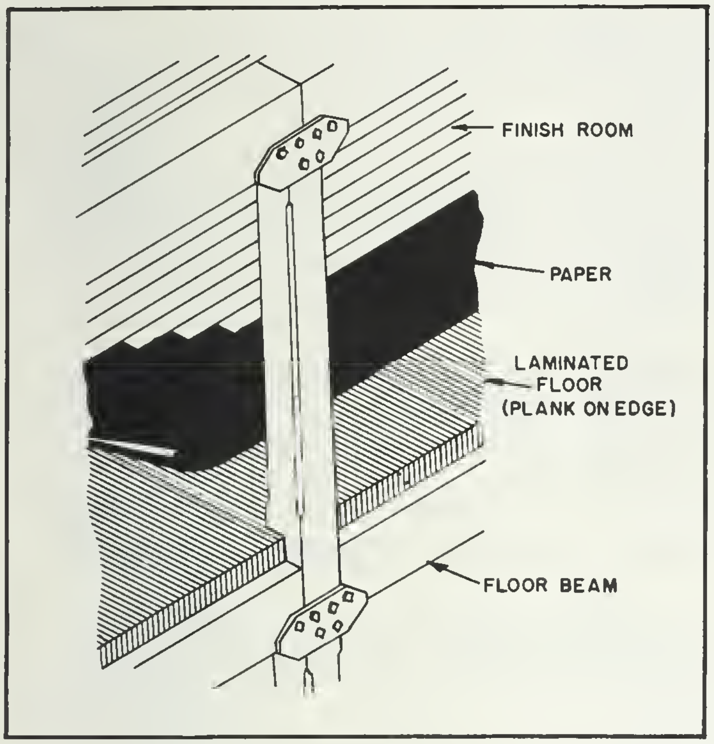


FIGURE 9-43
Laminated Floor and Beam Framing

c. Plank Floor, Beam, and Girder Framing. Plank floor, beam, and girder framing (termed semi-mill construction) consists of floors of heavy plank that are laid flat upon large beams. The beams are spaced from 4 to 10 feet on centers and are supported by girders spaced as far apart as the loading will allow. Carry these girders on wood posts or columns located as far apart as is consistent with the basic design of the building. Usually, space the columns from 20 to 25 feet in this class of framing where the loading is not excessive.

d. Minimum Thicknesses. See National Fire Protection Association (NFPA) Standards for criteria such as minimum thicknesses and sizes, framing connections, surface treatments, and related items. (See Criteria Sources.)

e. Joist and Girder. Use the joist and girder system for light to medium loads, with hung ceilings, for fire protection. The joist and girder system should be avoided in exposed construction because of inherent fire hazards presented by a multiplicity of corners and soffits.

f. Truss and Purlin. Use truss and purlin for roof construction with standard timber connectors as shown in Figure 9-1. The bowstring truss has the advantage of using small pieces because the

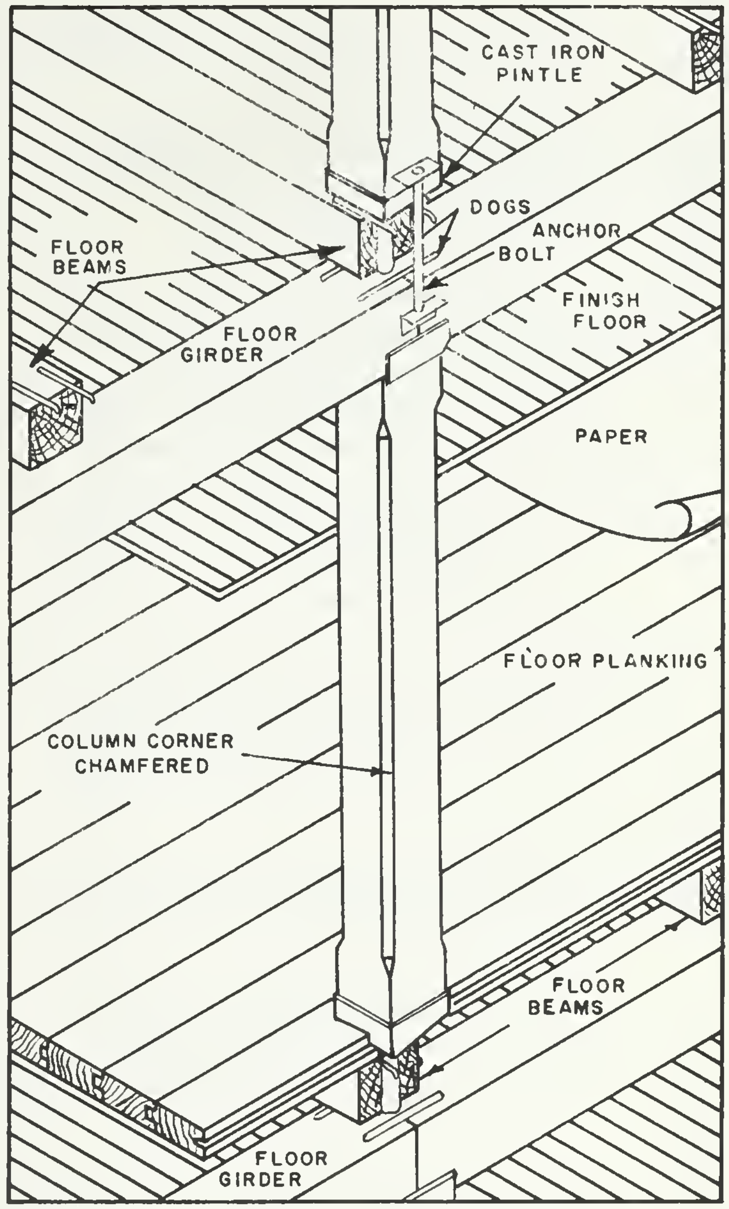


FIGURE 9-44
Plank Floor, Beam, and Girder Framing

chords can be built of 1- or 2-inch pieces that are nailed, bolted, or glued together.

g. Glue Laminated Members. Form glue laminated beams, columns, or arches from stock having 1- or 2-inch nominal thicknesses.

(1) Advantages. The use of glue laminated members offers the following advantages:

(a) Members may be built to any desired cross section, length, or shape.

(b) It is possible to build up members from material too small to be structurally useful otherwise. Also, smaller pieces are more quickly dried or seasoned and experience less degradation from the seasoning process.

(c) Laminations may be positioned according to strength characteristics. Material of

lower grade may be used in a portion of a member where stresses are low, and higher or better grades may be placed where maximum stresses occur.

(d) It is easy to camber laminated beams during construction, and the undesirable appearance that often results from sagging green timbers, allowed to season under load, is eliminated.

(e) In certain types of trusses, the curved top chord can be made continuous through the panel points, thus simplifying fabrication.

(f) It is possible to build large wooden arches using a single cross section for the arch rib. This type of construction is more resistant to fire than a truss or arch built of individual pieces, designed to carry the same load.

(g) Glue joints can be made as strong as the wood itself.

(h) By the use of glues, resistant to both water and heat, timber material and plywood can be satisfactorily pressure treated after gluing. For a preservative, use either water-soluble salts or coaltar creosote.

(1) Disadvantages. Disadvantages resulting from the use of glue laminated members are outlined as follows:

(a) Pressure and temperature must be accurately controlled during gluing operations.

(b) The use of skilled workmen and controlled working conditions is mandatory.

(c) Almost all work must be shop fabricated.

(d) The member length is dependent on transportation facilities.

h. Arches. Wooden arches can be either open or solid web. Open web arches have joints and details similar to those in trusses. Solid web arches are glue laminated. The following requirements apply:

(1) Use three hinge arches to achieve maximum advantage in fabrication, transportation, and erection.

(2) Use arches in conjunction with purlin construction or long span metal deck.

(3) Use wooden arches in structures where inherent attractiveness of exposed wood construction is especially advantageous.

Part 4. OTHER STRUCTURES

1. TIMBER-CONCRETE COMPOSITE DECK. Use timber-concrete composite deck in bridge decks, piers, docks, warehouses, ramps, and other structures requiring heavy-duty floors (Figure 7-2). Follow the procedures and details indicated in Chapter 7.

2. CRIBS. Use 8- by 8-inch timber and 5/8-inch-diameter bolts for the construction of cribs. Use creosoted timber unless the structure is for temporary use.

3. WATERFRONT STRUCTURES. Criteria for the construction of waterfront structures are contained in *Waterfront Operational Facilities*, NAVFAC DM-25.

Part 5. SPECIAL CONSIDERATIONS

1. FIREPROOFING. Criteria related to fireproofing are contained in Section 1.

2. DECAY FUNGI. Incorporate the following procedures to avoid decay caused by fungi.

(1) Use dry lumber and insure rapid rain runoff to keep lumber dry.

(2) Use preservative treated wood or heartwood of decay-resistant species.

(3) Remove stumps, wood debris, stakes, and concrete forms from the building locality.

(4) Avoid storage of timber in direct contact with the ground.

(5) Provide an 18-inch minimum crawl space under basementless structures. Make joist and girder masonry pockets large enough to insure adequate air circulation. Lay roll roofing over soil to minimize condensation.

Section 6. OTHER STRUCTURAL SYSTEMS

1. TYPES. Other structural systems consist of precast ledger beam, joist and slab, floor lath, insulated formboard, and lamella roofs. For description and characteristics of these systems, refer to Table 9-5 and Figures 9-45 through 9-48.

2. SELECTION FACTORS. Requirements and applications to be considered in selecting structural systems are listed in Table 9-6.

Section 7. SLANTING CONSTRUCTION

1. BUILDING FRAMES.

a. Shear Wall Structures. Limit widths of buildings to one-third the lengths. If lengths are

TABLE 9-5
Other Structural Systems

Type	Description	Loads[1] psf	Spans[1]	Remarks	Fig. No.
Joist and filler.	Concrete precast joists, precast fillers, cast-in-place topping.	Varies	Varies	No ceiling finish required.	9-49
Floor lath.	Paper-backed reinforcing fabric.	100-400	18-36 in.	Eliminates formwork on joist-supported concrete slabs.	9-50
Insulatec form-board.	Permanent formboard for use in subpurlin supported gypsum or lightweight concrete.	10-40	32 in. joist spacing	No additional finish required, acoustic treatment built-in.	9-52
Lamella roofs.	Curved roof made of short timber pieces.	10-40	30-100 ft.	Short pieces can be used; no glued joints—all bolted architecturally pleasing.	9-51

[1] Loads and spans represent an economical range of values for the particular type of construction under the normal design conditions.

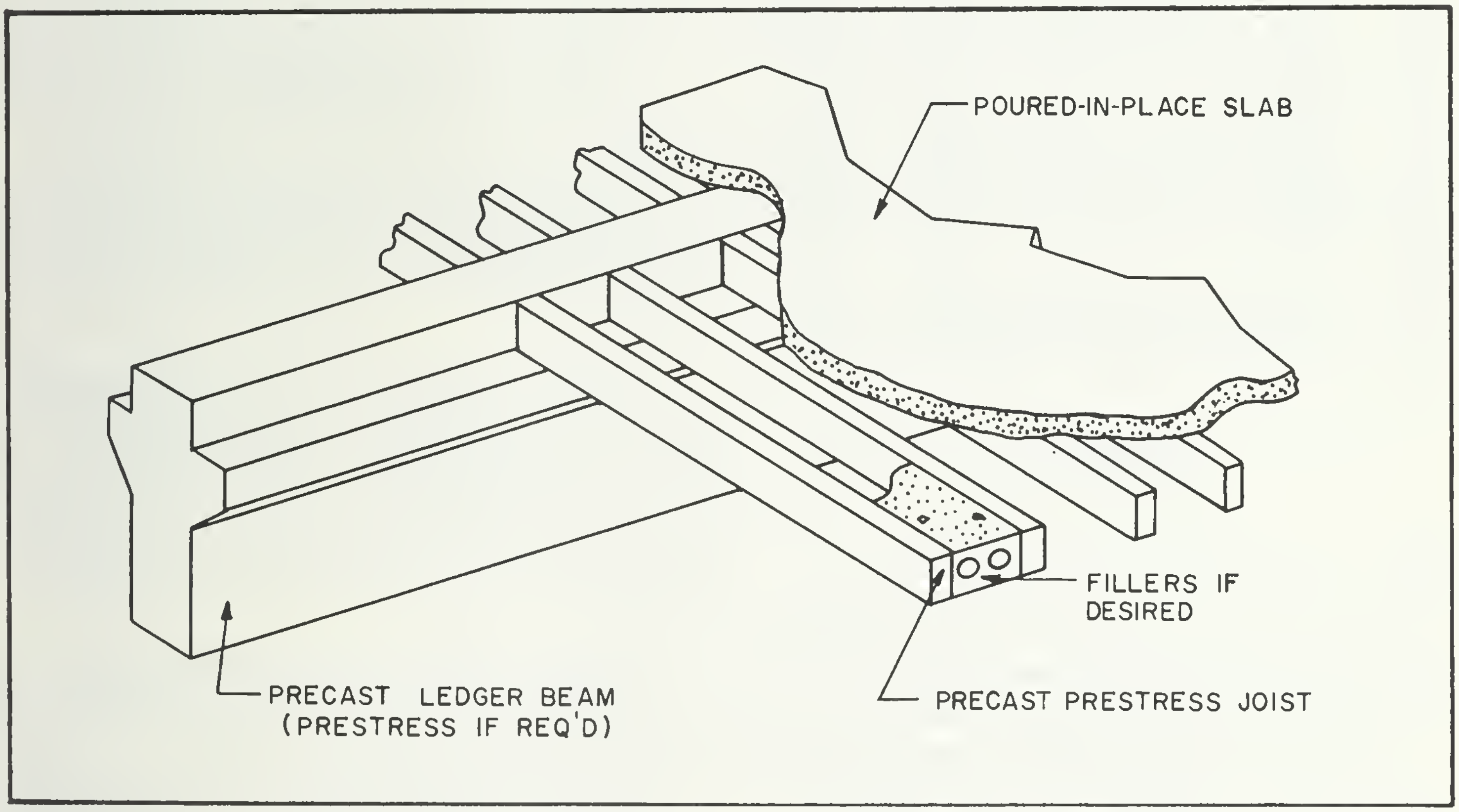


FIGURE 9-45
Precast Ledger Beam, Joist, and Slab

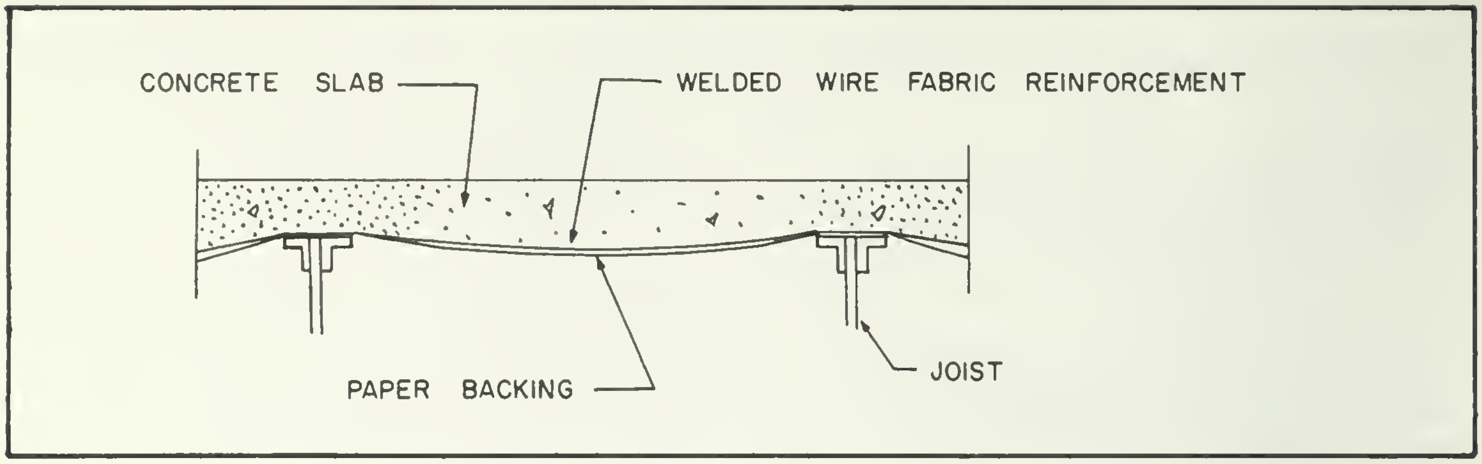


FIGURE 9-46
Floor Lath Construction

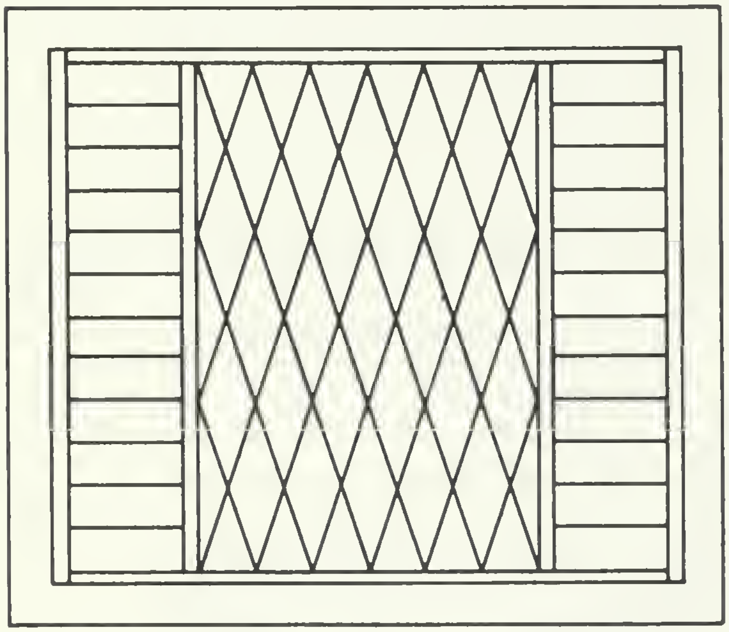


FIGURE 9-47
Lamella Roof Plan

excessive, install transverse shear walls at spacings not exceeding three times building widths.

b. Main Framing. The following must be considered when designing main framing:

(1) Use series of rigid bents, continuous frames, arches, or shear walls.

(2) In general, frames shall span lesser dimensions of buildings, providing strength in weaker directions of structures.

(3) Where possible, eliminate the use of simply supported members.

(4) Framing shall be reinforced concrete or structural steel. Reinforced concrete can be cast-in-place, precast, or prestressed. Steel framing should be of welded construction.

c. Secondary Framing. Connect secondary framing to main framing by either rigid connections or full member continuities over supports. In steel framing, obtain desired continuities for purlins and girts by lapped arrangements over the supports. Such arrangements should provide both continuity and efficient utilization of framing materials.

d. Additional Reinforcements. In cast-in-place concrete construction, to assure full strengths and continuities of monolithic pours, provide additional reinforcing at supports for moment resisting capacities; not less than 50 percent of these at member midspans. Make some top steel continuous across full-member spans.

e. Joints. Connections between columns and foundations shall develop moment strengths not less than those corresponding to 50 percent fixity at bases. Design all frame joints for moment and shear resisting capacities, particularly those joining vertical and horizontal elements at the exterior skeleton.

f. Minimum Connections. When providing minimum connections, develop full strengths of sections, whether major or minor members.

g. Bracing. Provide additional bracing, where feasible, to increase frame rigidities.

2. ROOF CONSTRUCTION. Slabs and girders used in roof construction shall conform to the following requirements.

a. Slabs. Use concrete slabs poured monolithically with supporting concrete members or

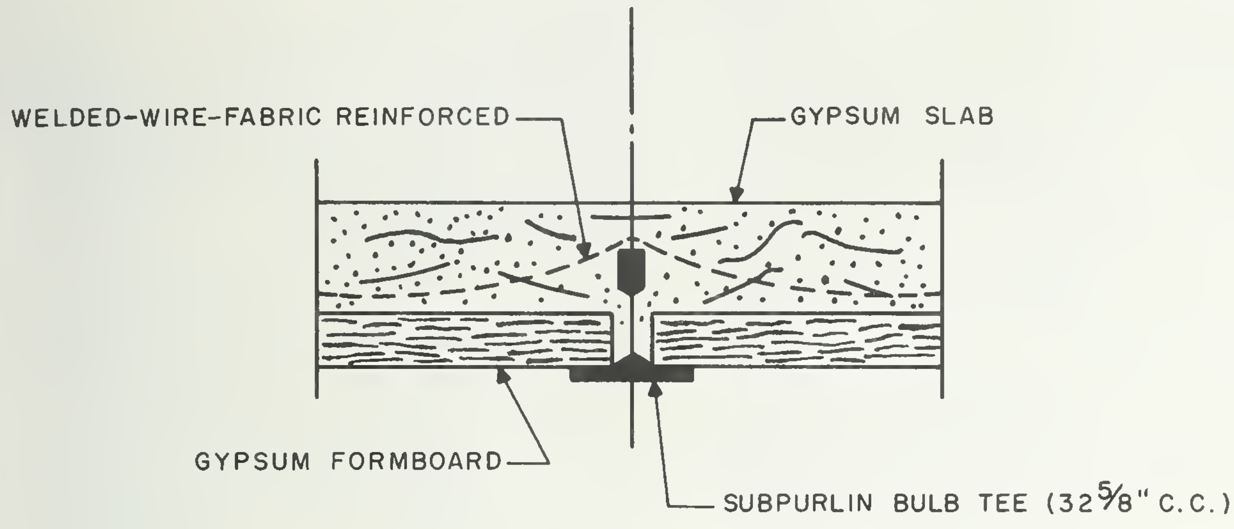


FIGURE 9-48
Insulated Formboard with Poured Gypsum Roof Slab

secured to supporting steel members. Design for full continuities over supports. Provide precast concrete panels with rib stiffeners and anchored metal inserts for welded connections.

b. Girders. When installing roof girders, provide top and bottom continuous reinforcing, tied together with stirrups throughout span lengths. Extend bottom reinforcing into supports, anchors, or splices for full continuities.

3. WALLS. Use moment- and shear-resistant framing or panels. Avoid unreinforced brick or block construction. Provide anchorages to foundations to resist uplift and overturning of walls.

4. FLOOR CONSTRUCTION.

a. Cast-in-Place Concrete Slabs on Steel Beams. Floor slabs shall be integrated with beams or stringers. For concrete slabs with steel beams or stringers, provide slabs with sufficient reinforcing in the bottom faces to develop positive moment strengths over supports equal to one-half those of design negative moments. Slabs shall be securely anchored to supports to prevent shear slippage or pullout.

b. Precast Concrete Slabs. Design all precast concrete floor slabs with stringers to form integral panels. Make connections of floor panels together and to main frames by cast metal inserts welded together in final assemblies.

c. Basement Ceilings. To resist weights of collapsing superstructures, provide adequate strengths to floor slabs that serve as ceilings of basement levels, where economically feasible.

Section 8. EQUIPMENT SUPPORTS

1. LOADS. Increases in live loads to provide for the impact allowance for reciprocating and rotating machinery are outlined in Chapter 1.

a. Torque Loads. Torque loads are produced by magnetic reactions of electric motors and generators which tend to retard rotation. Use five times the normal torque in the design of the supporting members. For turbine generators, normal torque may be computed by equation (9-1),

$$\text{torque (ft lb)} = \frac{7{,}040\ (\text{kw})}{\text{rpm}}. \qquad (9\text{-}1)$$

For other types of rotating machinery, similar formulas may be used.

b. Inertia Forces. When computing load requirements and equipment supports, consider the

TABLE 9-6
Structural System Selection Factors

Factor	Requirement	Applications
Duplication and subassemblies.	Use duplications to reduce unit costs and handling.	Make concrete roof beams same as lower floor beams to reuse forms. Avoid different reinforcement bar sizes in beams.
Labor classes.	Reduce overall costs by proper labor choices.	Minimize field work, intricate assemblies, and details involving expensive labor. Use field bolted connections in lieu of rivets or welds, if possible.
Operation sequences.	Use operations allowing uninterrupted work flow of all trades.	Avoid steel framed structures bearing on walls, where framing depends on wall construction.
Erection and shipping.	Limit component sizes and weights to equipment capacities.	Use shorter members with additional splices. Do not use rib slabs requiring steel forms shipped long distances. Use flat slabs. Use short span concrete slabs with self-supporting forms or hung forms to eliminate shoring. Use precast concrete slabs for one story high roofs.
Life of structure.	Use systems compatible with service lives of structures.	Satisfy minimum requirements only for strength and utility with no frills. Obsolescence, not deterioration, determines replacement. Only if service life is unknown, build better.
Rot and corrosion.	Depends on expected service life.	Where required, use preservative treatments for timber. Galvanize all steel hardware for waterfront structures.
Insects.	Use necessary precautions in wood construction, if no substitute materials are available. Should use concrete construction.	Use preservative treatments for essential timber construction.
Climatic influence.	Use systems compatible with environments.	Protect structures with vapor barriers. Avoid cast in place concrete construction in cold areas.
Fire resistance.	Use inherently fire-resistant materials.	Use concrete framing systems to eliminate need for additional protection. Use vermiculite protected, steel-frame systems where dead loadings are important.
Deflections.	Minimize permanent deflections.	Use dried timber. Camber long spans of steel frame structures.

effects of inertia forces created by reciprocating motion or unbalanced rotating parts.

2. VIBRATION. The supports for high-speed machinery of great vibrational tendency, such as turbogenerators, turbine-driven or motor-driven pumps and fans, and motor generators, shall be designed to reduce vibration to a minimum.

a. Deflections. Design the beams or girders supporting machines so that the maximum deflection will not exceed 1/50 of the span (impact included), with the span taken as the distance, center-to-center, of the columns and the ends considered as supported without restraint. The structure shall be designed so that a horizontal transverse force, equal to one-half of the weight of the machine, applied at the level of the shaft, will not

produce a deflection greater than 1/50 of an inch at the base of the machine.

b. Isolation. Consider the use of vibration and shock isolators to reduce the magnitude of the force transmitted to the supports for the machinery. Isolation criteria are listed in *Mechanical Engineering*, NAVFAC DM-3. Consider the use of vibration absorbers where it is required to eliminate vibration of the supporting structure.

3. FOUNDATION CONSIDERATIONS. Foundations for vibrating machinery require careful consideration. See *Soil Mechanics, Foundations, and Earth Structures*, NAVFAC DM-7, for the resistance of different types of soils to vibratory loading and the determination of the natural frequencies of foundation soil systems.

a. Foundation Weight. The minimum weight of the foundation shall be 1.5 times the weight of the vibrating machinery. In determining required foundation weight, consider the proportion of the weight of the rotating or reciprocating part of the machine to total machine weight and the restrictions on lateral movement of the foundation.

b. Isolation of Foundations for Vibrating Machinery. Foundations for heavy machinery should be completely isolated from foundations and floors of the building. The gap between the machine foundation and other construction should be at least 1 inch. This gap shall be maintained clear or filled with a soft plastic material. The bottom of the machine foundation shall not be above the foundations of any neighboring buildings.

Section 9. CONSTRUCTION IN AREAS OF HIGH WINDS

1. SCOPE. The criteria and recommendations contained herein shall be used, when applicable, in the design of facilities for areas subject to typhoons, hurricanes, and other high winds in excess of 90 miles per hour. In this Section the term "hurricane" shall be considered as applying to all of the various high wind storms. This Section is in addition to the pertinent criteria in Chapter 1, and is provided to insure that extra attention will be given to those details of design where failures due to wind storms have been repeatedly experienced.

2. DESIGN. Structures and facilities of concrete, steel, and timber will continue to be the main materials for construction world-wide within the foreseeable future. Concrete is an inherently hurricane-resistant medium and is usually the preferred material for such areas. However, some of the following recommendations apply equally to concrete as they do to steel or timber construction. Each must be designed for structural integrity so that all of the elements are put together to provide continuity from roof to foundation. Of equal importance, inattention to details, such as poor attachment at the roof edge, has resulted in the loss of an otherwise sound structure when wind gains entrance into the structure and increases the uplift forces on the roof. Resistance against uplift must be provided at all critical connections. It is false security to design walls and windows to withstand winds of 150 miles per hour when the roof anchorage can resist only the uplift caused by winds of 80 miles per hour.

a. Future Recommendations. Recommendations will be added to this Section, based on observations made during and immediately following devastating storms. Users of this manual are therefore encouraged to forward their own observations to NAVFAC Headquarters for incorporation in future recommendations.

3. CONCRETE STRUCTURES. Use of unreinforced wall-bearing concrete or masonry, and simple support framing of structures, must be avoided in hurricane areas.

a. Cast-in-place. Reinforced concrete structures, with shear walls and rigid framing cast in place, are particularly suitable for areas subject to hurricanes.

b. Precast. Tilt-up precast reinforced concrete structures are also very hurricane-resistant, but require special attention to detail at points of attachment to assure structural continuity and watertightness.

c. Cover. Minimum concrete cover over reinforcement for the above conditions is specified in Chapter 3, Table 3-2.

4. STEEL STRUCTURES. In the design of structural steel framing members and their connections, full consideration must be given to the corrosive effects of the relatively high chloride content of the hurricane-borne rainwater. Protection from such cor-

rosion should be designed into the structure, rather than dependent entirely on field maintenance. Design consideration should also be given to provide access to critical members for periodic inspection and maintenance.

a. Curbs. Steel column bases and the bottom wall channels of steel framed structures will be placed on concrete curbs or on grade beams above finished grade to minimize corrosion.

b. Sheathing. Steel sheathing for steel framed structures should be either galvanized, enameled, or protective-coated to resist corrosion, and aluminum sheathing should be anodized. Other materials should be avoided for hurricane area use until proof of their survival is accepted. Sheathing fasteners should be compatible with the sheathing and provided with neoprene or composite metal and neoprene washers. The use of fasteners of a metal dissimilar to the sheathing will be avoided, unless nonmetallic washers are provided as isolators against electrolosis and corrosion. Fasteners for sheathing, prefabricated panel, or precast panel should be provided in adequate quantities to insure composite action between sheathing panel and framing, and to preclude detachment of sheathing. Special attention shall be given in the design of fasteners for interior metal lath and plaster walls, duct work, and fenestration to insure that differential pressures caused by the low-pressure area in the eye of a hurricane do not collapse the interior components of the building.

c. Curtain Wall Reinforcement. When masonry is used as the enclosing material (for example, a curtain wall), it will be reinforced both vertically and horizontally to withstand the design wind pressure. This reinforcement will be tied to the building framing system, both vertically and horizontally, and tied to matching reinforcing in the grade beam or floor slab.

5. TIMBER STRUCTURES. Although timber structures have generally suffered greater loss in hurricanes than structures made from other materials, their use is widespread and is probably on the increase in many areas. Study of surviving structures from recent storms has generated a number of "do's and don'ts," and the following are worthy of due consideration by designers for the construction of more hurricane-resistant items.

a. Overhanging Roofs. Designs incorporating slight-sloping or flat roofs with wide perimeter overhangs are particularly vulnerable to "nibbling" action leading to roof loss. The high uplift forces on overhangs can create a flutter action which may result in progressive raveling or nibbling at the connections.

b. Truss Advantages. Truss construction for roofs in hurricane areas has significantly greater resistance to failure than that of other roof systems.

c. Connections. Care should be exercised in design of ridge, roof-to-wall, floor-to-wall, and wall-to-foundation connections. Each of these critical locations forms a link in the continuity chain so vital to intact structural survival. Various manufactured connectors, clips, straps, and gussets are available for inclusion at each connection point, or can be easily fabricated if adequately detailed by the designer. Lack of such details has been found to be a major cause of structural failure. Connections employing nailing alone, especially toenailing and nails subject to withdrawal forces, must not be relied upon in hurricane areas.

d. Sheathing. Plywood sheathing, or diagonally laid board sheathing, inherently possesses more resistance to racking than most of the fiberboard types of sheathing.

6. COMMON ITEMS. The following are common to all construction materials.

a. Roofs. In the order of their resistance to high wind forces, cast-in-place concrete roofs are the best choice and precast concrete panels or slabs would be second. Since concrete roofs may be impractical for steel or timber structures, steel panels, plywood panels, or combinations are usually used. However, in all cases, special attention must be given to the attachment of roofs to supporting structural elements.

b. Windows. All window components, including hardware and anchors, must be designed for the designated wind load.

c. Protective Coverings. All windows should have either fixed or movable coverings to protect the fenestration from flying debris, and to improve the weathertightness of the buildings.

d. Jalousies. Project specifications should describe the test. In jalousies, the deflection of the blades should not exceed 1/180 of the span.

e. Doors. Nominal 3 by 7 foot doors, and double doors consisting of 3 by 7 foot doors, should be securely fastened to the head and sill by means of foot and chain bolts, or other approved fasteners. Prototypes of larger size doors should be tested to insure that the doors, when furnished on the job, will be structurally adequate.

f. Flashing. Flashing and fascia for roofing and for fenestration are particularly vulnerable to high winds, and should be adequately anchored.

g. Vents or Orifices. Buildings which are wholly or partially sealed for air conditioning sustain damage by differential pressures created between the interior and exterior of the structure. Therefore, vents, orifices, or jalousies with simple differential pressure controllers should be provided in buildings. Mechanical types of controllers are recommended. Openings for fresh air intakes and openings to supply and exhaust fans should be constructed so that driving rain will not enter the building.

h. Hoods and Ducts. Hoods and ducts mounted on the exterior surface of building roofs should be designed for a wind pressure of 2q, where q is the velocity pressure. Interior ducts of sheet metal should incorporate differential pressure controllers.

i. Chimneys and Stacks. Chimneys and stacks should be provided with water shields or caps that can withstand the wind pressure involved and can prevent entry of storm water.

7. PREFABRICATED BUILDINGS. Prefabricated buildings should be used discriminately. They should be designed in accordance with the wind velocity criteria for permanent structures. Structures incorporating interior walls which act as diaphragms are recommended. When prefabricated buildings are used as temporary structures, the design criteria for permanent structures are not applicable, provided no personnel or critical materials are housed in such buildings and that the buildings are not located adjacent to permanent structures. In addition, signs should be posted in such buildings requiring evacuation during hurricane or typhoon alerts. See *Seismic Design for Buildings*, Army, Navy, and Air Force manual NAVFAC P-355, for recommendations on diaphram design.

8. UTILITY POLES. Prestressed concrete utility poles are particularly suitable for areas subject to typhoons or hurricanes. In general, the design criteria for prestressed poles should be in accordance with the applicable provisions of the criteria for design of prestressed piles. The design of foundations for self-supporting poles, such as flagstaffs and telephone and electrical transmission poles, should take into consideration inundated soil condition.

9. DRAG STRUCTURES. Stacks and suspended pipelines require the following considerations.

a. Stacks. The determination of wind forces on tall stacks is a dynamic problem, because tall stacks vibrate under the action of high wind conditions.

(1) Nonresonants. Stacks should be nonresonant with the eddy frequency for all wind velocities.

(2) Stiffness. To increase the stiffness of stacks, the use of rigid bracing between the stack and adjoining stacks or structures should be considered.

(3) Frequency. The frequency of vibration of a stack should be considerably greater than the frequency of the wind vortices. To accomplish this economically, the stack can be designed as a frustum of a cone for its entire height.

(4) Damping. Advantages of the damping properties of shotcrete or concrete stacks and liners should be considered.

(5) Foundations. Pile foundations should be considered as energy dissipators for stack vibrations.

b. Suspended Pipelines. The oscillations due to both high and low wind velocities on suspended pipelines should be considered.

Section 10. INERTIAL GUIDANCE SYSTEM FOUNDATIONS

1. STABILITY REQUIREMENTS. Coherent and reliable stability requirements on which to base the design of foundations for a laboratory to test inertial guidance systems and their components do not exist. Foundation motion only affects testing of system components, accelerometers, and gyroscopes (gyros), and not the entire system. For convenience, foundation motions, both linear and angular, are divided into permanent sets, oscillations, and shocks.

a. Permanent Sets. Permanent sets cause errors in both accelerometer and gyro tests. However, with proper and frequent attention to the true direction of the vertical and the north-south line, the errors can be kept sufficiently small to meet present-day accuracy requirements.

b. Linear Oscillations. Linear oscillations are of concern in accelerometer calibration tests. A tentative requirement for maximum allowable linear acceleration for a platform is 10^{-5} gravity (g) in the frequency range $F < 0.02$ cps; 10^{-4} g in the frequency range $0.02 \text{ cps} < f < 2 \text{ cps}$; and 0.5×10^{-4} g in the frequency range $2 \text{ cps} < f$. The tentative requirements for tilting or rotational oscillations are a maximum tilting rate or angular velocity of 0.001 degree per hour for frequencies $f < 0.1$ cps, and a linearly increasing rate for higher frequencies such that angular velocity is 0.01 f degree per hour. A maximum angular deflection of 2 seconds should not be exceeded at any frequency.

c. Shocks. Shocks, or high frequency transients, can be more of a nuisance than an impediment to testing. Shock occurrence should be infrequent (less than one per minute), but their amplitude may be greater than that of sustained oscillations, perhaps by an order of magnitude.

2. FOUNDATION CONSTRUCTION. Depending upon the subsoil, select either a heavy slab or a pillar type of foundation for test equipment.

a. Independent Building Foundation. Design the foundation of the main building, floors, walls, and roof independent of the test foundation.

b. Motion Measurements of Test Foundations. Construct the test foundation and, before erecting the building, measure the motion of the foundation. These tests should run for not less than 24 continuous hours; and events, such as tides, shift changes, and passing trains, should be noted. In the case of a slab construction, the effect of people, forklift trucks, or other equipment moving over the foundation should be noted. If people, trucks, or equipment on the foundation cause serious disturbances, a separate floor, not touching the slab, should be planned. For pillar-type foundations, a separate floor should be provided. The criterion of acceptability should be a spectrum of the type indicated in Figures 9-49 and 9-50. This spectrum is intended for repetitive loads. Occasional loads or shocks, where the period is small compared with the average time between repetitions, might be permitted ten times the allowable amplitude of continuous oscillatory motion.

3. FOUNDATION TEST. For additional information, see *Stability Requirements for an Inertial Guidance System Test Facility,* SRI. (See Criteria Sources.)

a. Stability Measurements. After the foundation is poured, but before the building is erected, the stability should be measured to ascertain if separate flooring is necessary to reduce motion. Seismic instruments can measure only a limited range of the frequencies and amplitudes which are of importance in foundation motions. Therefore, well calibrated, sensitive inertial systems gryos and accelerometers should be used to measure linear motions to 10^{-5} g in the frequency range of 0.01 cps and angular velocities as low as 0.001 degree per hour up to 0.1 cps, with a linearly increasing lower limit of angular velocity at higher frequencies.

b. Vibration Mounts. The use of vibration mounts under test platforms is recommended only where it is necessary to remove high frequency oscillations.

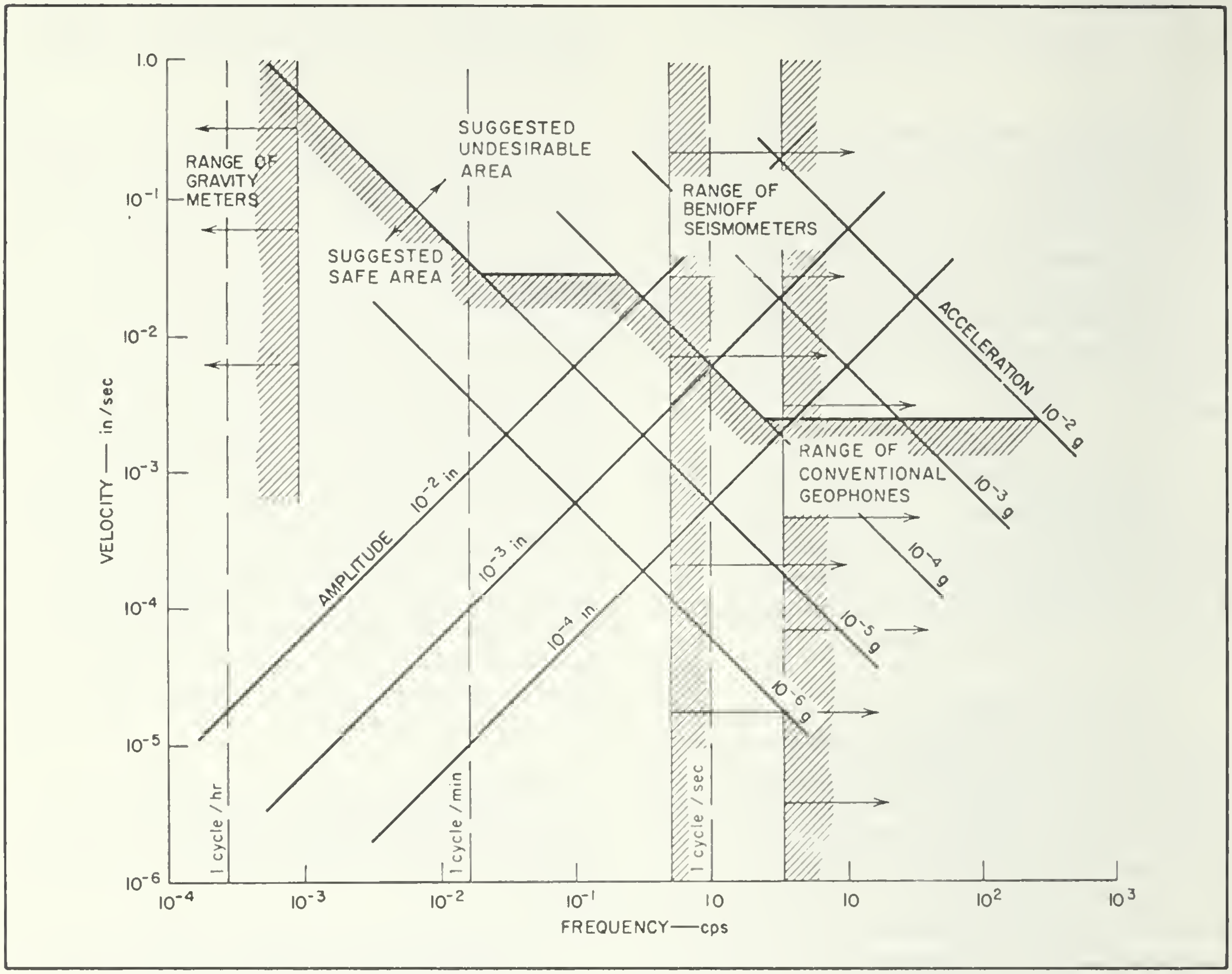


FIGURE 9-49
Relations Among Amplitude, Velocity, Acceleration, and Frequency in Linear Oscillations

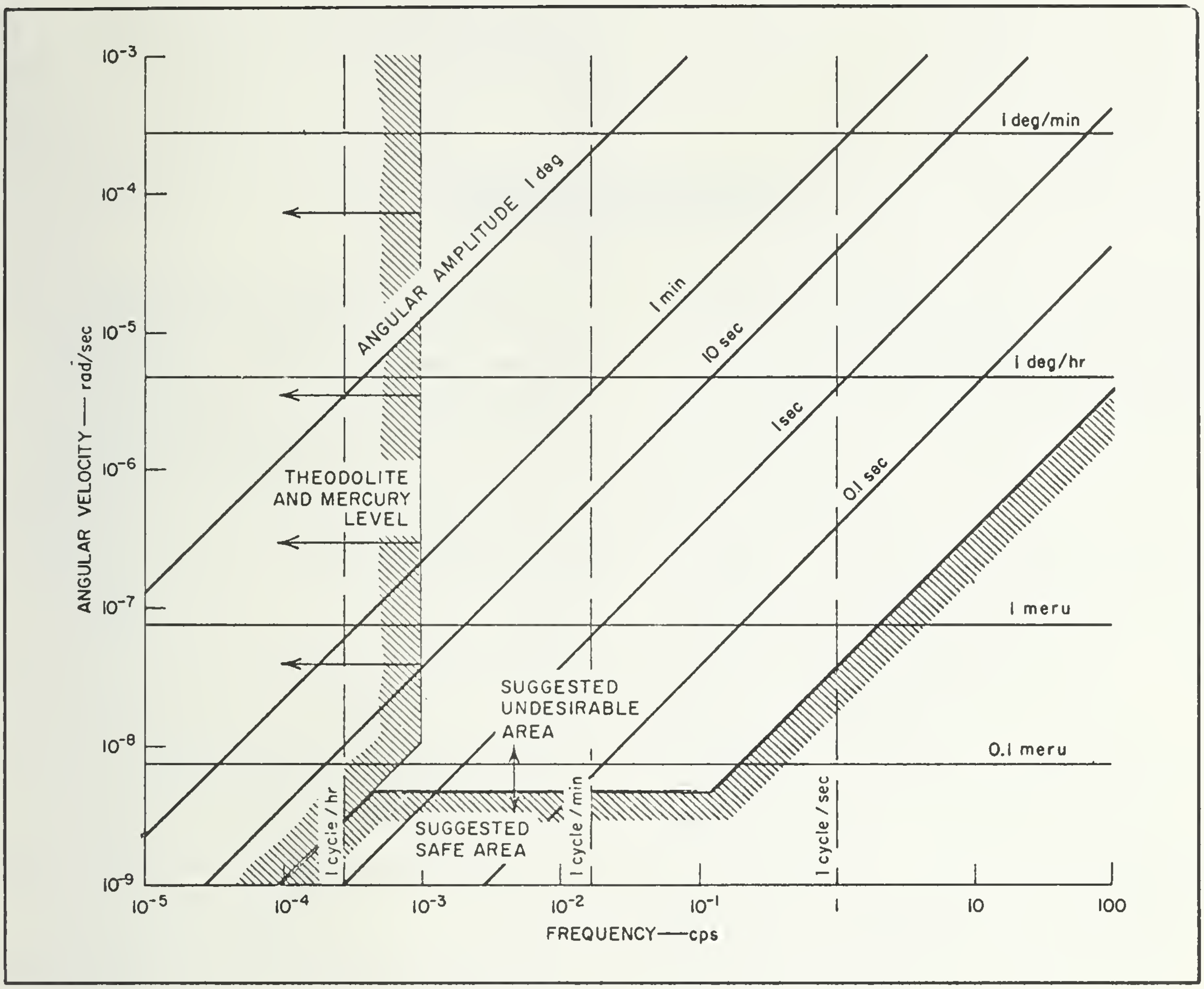


FIGURE 9-50
Relations Among Angle, Angular Velocity, and Frequency for Rotational Oscillations

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GLOSSARY

Bent. Transverse system of framing composed of columns and beam(s).

Bolster. Short wooden piece used to give larger bearing area for supported beams, and so on, at top of columns.

Camber. Slight vertical curve built into beams, trusses, and so on, to offset load deflection.

Check. A lengthwise separation of wood which usually occurs through the rings of annual growth.

Cladding. Composite plate made of base metal with a plate of corrosion- or heat-resistant metal on one or both sides.

Cover. The thickness of concrete between the outer surface of a reinforcement and the nearest surface of the concrete.

Creep. A slow deformation under stress.

Dap. Notches in timber to provide flat bearing surface.

Deadman. Anchorage below the ground surface.

Drift Bolts. Bolts used to connect members by driving into a prebored hole of smaller diameter.

Fatigue. A type of failure in metal resulting from repetitive loading.

Furring. Flat pieces of timber used to bring an irregular framing to an even surface.

Galvanize. To coat steel or iron with zinc.

Grout. Mortar thinned by addition of water.

Gunite. Pneumatically placed concrete.

Guy. Cable for holding a structure in a desired position.

Honeycomb. Voids in concrete.

Izod. Type of impact test in which a specimen is struck by a swinging pendulum and the energy absorbed in the fracture is measured.

Laminate. Plies of wood joined together with an adhesive or mechanical fastenings, or both.

Monitor. Vertical roof projection for providing light and ventilation.

Rigid Frame. A rigid joint structure in which moments and shears in joints maintain the equilibrium of the structure.

Resonance. Condition reached when frequency of applied dynamic load coincides with natural frequency of load support.

Scarf. A type of joint in which the surfaces to be joined are bevelled and lapped.

Shear Castellation. Set of interrupted keys cut into wood used to provide shear strength at junction between dissimilar materials in composite construction.

Sheathing. Close boarding nailed to the framework of a building to form the walls or the roof.

Shoring. Props of timber or other material in compression placed temporarily to support beams, etc.

Slanting Construction. Type of construction in which blast and/or bomb resistant features are incorporated into new structure without appreciable extra cost or reduction in efficiency.

Soffit. The underside of members and parts of structures such as beams, arches, staircases, comices, etc.

Tendon. Prestressing strands and wires used in prestressed concrete.

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